HAND-BOOK

OF

CYCLONIC STORMS IN THE BAY OF BENGAL.

THACKER, SPINK & Co., CALCUTTA.

List of the more important errors in the Hand-Book of Cyclonic Storms in the Bay of Bengal, Vol. I. with their corrections.

[*N. B.*—It would probably be desirable to make these corrections without delay in the book itself.]

Page.	Para.	Line.	Correction.
iv	1	5	*For* "Richard Frers'" *read* "Richard Freres'."
26	6	4	*For* "on position of pressure to west" *read* "or position of lowest pressure."
27	6	3 & 4	*For* "in the next chapter" *read* "in the third chapter."
27	8	6	*For* "direction of the sleepest" *read* "direction of the steepest."
27	Fig. 8		*For* "Direction of steepes gradient" *read* "Direction of steepest gradient."
46	6	10	*For* "requent comparison" *read* "frequent comparison".
48	2	4	*For* "oi fall of the barometer" *read* "or fall of the barometer".
53	3	1	*For* "pressure o" *read* "pressure of".
60	2	1	*For* "of one-tenth of an inch" *read* "of one and two-tenths of an inch."
70	3	2	*For* "In that case it is almost" *read* "In that case the sun's heat is almost."
71	1	1	*For* "experted in each month" *read* "expected in each month."
73	1	25	*For* "is and therefore yielding" *read* "and is therefore yielding."
92	3	2	*For* "the, Bay with the result" *read* "the Bay, with the result."
95	1	2	*For* "in Plates III to xvi" *read* "in Plates III to xviii."
98	2	7	*For* "the winds blew from west" *read* "the winds blow from the west."
111	1	1	*For* "In the preceding chapter" *read* "In the first chapter."
111	2	1	*For* "In the preceding chapter" *read* "In the first chapter."
112	2	8	*For* "the most intense storms in the Bay" *read* "the most intense storm in the Bay."
113	3	7	*For* "the south of the Bay and curve" *read* "the south of Bay, curve".
115	1	4	*For* "In the concluding summary" *read* "In the brief summary."
115	2	2	*For* "The character of the smaller cyclonic storms of the rains had" *read* "The character of the smaller cyclonic storms of the rains has".
115	2	7	*For* "very rarely, ever" *read* "very rarely, if ever".
120	2	4	*For* "cyclone of September 1887" *read* "cyclone of September 1885".
129	1	2	*For* "in the preceding chapter" *read* "in first chapter."

Page.	Para.	Line.	Correction.
130	2	8	*For* "The False Point traces" *read* "The False Point trace."
131	7	6	*For* "which move" *read* "which moves."
164	1	15	*For* "the more dangerous storm" *read* "the more dangerous storms."
171	2	4	*For* "change whether" *read* "chance whether."
171	3	4	*For* "Plates xxiii and xxxii" *read* "Plates xxiii and xxx."
195	2	8	*For* "large storms" *read* "larger storms."
199	3	6	*For* "(more especially where combined" *read* "(more especially when combined".
216	1	1	*For* "fore-end" *read* "fore and main."
238	2	2	*For* "the whole of this storm" *read* "the whole of these storms."
242	1	1	*For* "originated and was generated" *read* "originated or was generated."
251	2	10	*For* "in Lat. 11° 55′ E and 83° 56′ E" *read* "in Lat. 11° 55′ N and Long. 83° 56′ E."
291	4	11	*For* "In the Andaman Sea was" *read* "in the Andaman Sea were."
293	2	8	*For* "*S. S. Pandua*" *read* "*S. S. Pundua.*"
294	Last	5	*For* "by an east-north-east path" *read* "by a west-north-west path."
299	3 (3)	1	*For* "In the area to the north of west of the srorm" *read* "In the area to the north and west of the storm."

HAND-BOOK

OF

CYCLONIC STORMS IN THE BAY OF BENGAL.

FOR THE USE OF SAILORS.

VOL. I—TEXT

BY

JOHN ELIOT, M.A., F.R.S., C.I.E,

METEOROLOGICAL REPORTER TO THE GOVERNMENT OF INDIA AND
DIRECTOR GENERAL OF INDIAN OBSERVATORIES.

SECOND EDITION.

Published by the Meteorological Department of the Government of India.

CALCUTTA:
PRINTED BY THE SUPERINTENDENT OF GOVERNMENT PRINTING, INDIA.
1900.

Price Four Rupees.

CALCUTTA:
GOVERNMENT OF INDIA CENTRAL PRINTING OFFICE,
8, HASTINGS STREET.

PREFACE TO THE FIRST EDITION.

THIS work has been prepared for the information and guidance of sailors navigating the Bay of Bengal. It gives all the more important facts and results of the information that has been collected by the Calcutta Meteorological Office during the past twenty years, chiefly from sailors, respecting storms in the Bay of Bengal. It hence represents what may be termed the present working capital of that office used in its work of forecasting storms. The author has endeavoured to give the facts and results without any reference or bias to any particular theory of cyclone generation and motion. He has also made the rules for the practical guidance of sailors as precise and definite as possible. A vague rule, more especially, if intended for action in time of danger, is almost as unsatisfactory as no rule at all. It has, however, been carefully pointed out to what extent and from what causes the rules and indications given for guidance are likely, so far as can be judged, to fail. The author has also endeavoured to point out in what directions sailors can assist in taking weather observations in the Bay of Bengal with a view to assist in improving our knowledge of the laws of storms as applicable to that area. There are several rival theories of cyclone formations and motion in the field, and it is only by the collection and examination of more and more exact observations made by persons who take a keen and intelligent interest in the subject that it will be possible to test these theories and to select finally a correct and adequate theory.

Hence, whilst one object of the work is to give sailors a full statement and explanation of what must be called "the laws of storms in the Bay of Bengal" for their practical guidance, another is to induce sailors to observe accurately and fully the weather in the Bay of Bengal in the hope that they will send in copies of their observations to the Calcutta Meteorological Office, where they would be carefully considered and every fact likely to be of practical or theoretical use carefully noted and recorded.

The subject is even yet in its infancy, and the present work is for that and other reasons confessedly imperfect. It is to be feared there

are many mistakes in the book, although every effort has been taken in the enumeration of the very large amount of information which has been accumulated in the Calcutta Meteorological Office, and in drawing up the various tables and charts to ensure accuracy. The author will be grateful to any one pointing out errors of any kind and more especially to Captains acquainted with the weather and other conditions of the Bay of Bengal who will give him at any time information for, or against any of the inferences, indications, or rules stated in the book for guidance in forecasting or ascertaining the position, track or intensity of storms in the Bay. Any information of this kind, sent in to the Meteorological Reporter, Meteorological Office, India, Calcutta, will receive the fullest consideration and be utilized in the preparation of the next edition of the work, which it is proposed to issue if it is found that the present is of practical value to sailors navigating the Bay of Bengal.

PREFACE TO THE SECOND EDITION.

As the supply of the first edition is exhausted, it has been decided by the Government of India that I should issue a second edition of the work. I have received numerous suggestions for the improvement of the work, and have, so far as I could, adopted those which it appeared to me, would improve the work. The information has, so far as possible, been brought up to date. An additional chapter has been given stating briefly the chief features of the weather, winds and currents in the Bay, month by month, during the year. It is hoped this chapter will be found useful and will increase the interest of the study of the Plates or Charts III to XVIII showing pressure, winds, and currents in the Bay.

Chapter IV has been expanded by the addition of accounts of the Port Blair cyclone, most interesting on account of its very large recurvature, and the Chittagong cyclone of October 1897, the most recent severe Cyclone in the Bay. Some errors have been corrected, more especially in the last chapter.

It was my original intention to re-write the work entirely, but the various demands on my time have unfortunately prevented this. I had wished to reconsider the whole question of cyclone phenomena from the standpoint of recently accumulated information, but this would have required an amount of time I could not give consistently with my other duties as Meteorological Reporter to the Government of India, and Director General of Indian Observatories. The work is hence issued with the slight improvements mentioned above, but with its original defects of form and method.

I hope that this edition may be found as useful as I have been informed by many sailors that the first edition has been, and that the employment of its information in addition to their own experience by sailors navigating the Bay of Bengal may protect them from the dangers of cyclones in that sea.

I venture in this connection to express my opinion that we have still too much theory and too little accurate information of the details

of cyclone phenomena. Progress hence depends more upon accurate registration of phenomena by sailors than upon the discussion of theories. If these pages induce sailors to assist in this work and to use the aid of the simpler, cheap and effective continuous-registering instruments for measuring air pressure and temperature (*e.g.*, Richard Frers' barograph and thermograph) now available, one of my objects in writing the book originally will be attained.

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HAND-BOOK

OF

CYCLONIC STORMS IN THE BAY OF BENGAL

FOR

THE USE OF SAILORS.

INTRODUCTION.

THE chief object of this volume is to give the mariner who navigates the Bay of Bengal an account of the dangerous storms that occur in it, to state and explain the signs and indications by which he may recognize when he is approaching a cyclone, or that a cyclone is forming in that part of the Bay which he is traversing, and to furnish him with information and methods by which he may ascertain sufficiently for all practical purposes the bearing or direction of the storm centre, and the path of any cyclonic storm he may meet with in the Bay.

By following these or similar instructions he will, in the great majority of cases, if not in all, when he is involved in cyclonic weather in the Bay of Bengal, be enabled to avoid the inner storm area of dangerous winds, and fierce squalls and rapid shifts of wind.

I may here point out that my aim throughout the book has not been to give hard and fast rules, the observance of which will enable any seaman to pursue the safest course when he meets with a cyclonic storm in the Bay of Bengal. I do not believe it is possible to draw up rules which will be of use without the co-operation of the full intelligence of the person who wishes to employ the experience embodied in any series of rules drawn up for his guidance.

Hence throughout the book I have endeavoured to give reasons for every rule in the hope that I may enlist the intelligent co-operation of all who read it. The knowledge of many of the more important features of cyclone movement, development, and decay is as yet very imperfect, and it is mainly by the intelligent observation of those sailors who chiefly experience the birth, development, and movement of the cyclonic storms in the Bay of Bengal that further increase of our knowledge will be made. They supply the raw material for meteorologists to consider, discuss, and embody in rules for guidance.

The following remarks extracted from a paper read before the Shipmasters' Society on "The value of meteorological observations at sea and some hints upon them" by M. W. Campbell Hepworth, Master Mariner, Lieutenant, R.N.R., and from the subsequent discussion shew that my views in this matter are at one with those of many practical sailors :—

"Since becoming a member of the Shipmasters' Society, I have read with increasing interest many of the valuable papers upon subjects connected with our profession, which from time to time have been read before the members of this Society ; and have been impressed in their perusal by this fact, that a change is taking place in the mental attitude of responsible officers in the mercantile marine of this country in regard to matters relating to their business, such as trim, stability, distribution of weight in loading, and the handling of vessels under various conditions, and also in regard to many of the multitudinous details which are essential to their safe navigation ; that ideas and methods formerly in vogue which in the past have been considered to give satisfactory results, are now being looked upon with coldness, if not with positive disfavour, and are giving place to systems more concise and more scientific, and to yearnings after higher standards. *For my own part I can think of no calling where mathematical precision and physical knowledge will bear more momentous results, or more surely command success than that of the seaman,* or where the reverse tends more fatally towards the offering of sacrifices to the Moloch of stupidity and superstition."

The following remarks are extracted from the subsequent discussion on the paper :—

"My experience goes to show that a knowledge of first principles, be it ever so elementary, is infinitely more satisfactory than, and quite as easy as, rule-of-thumb. A shipmaster taking an active interest in meteorological matters at sea is not only keeping himself posted up to date, but also training those under him in the way they should go. Unfortunately junior officers occasionally get disgusted with four-hourly records for a special log-book, and the result leaves something to desire. This is only natural where the master does nothing more towards the work than keeping up the correspondence with the authorities. The very best meteorological log-books have either been kept solely by the masters, or by the officers in close co-operation with them ; one volunteer is worth two pressed men, even in this branch of seamanship. In our salad days we are apt erroneously to regard the minutes wrested from our watch below as of more importance than the attainment of vaguely defined "perceptivities", Ships' log-books might often be made more worthy of a British certificated officer. They would then be useful for weather discussion, even though the instruments are per specification."

"Captain Hepworth's paper should impress upon the rising generation of officers the necessity for an acquaintance with the elementary laws of nature. Human nature, and the comparatively moderate requirements of the Board of Trade, are, however, factors in the problem not to be ignored nor denied."

It is hardly necessary to remind sailors that the storms which are met with in the Bay of Bengal are occasionally of excessive violence. Formerly when little or nothing was known of the laws of storms, they caused frequent grave destruction to shipping. The following brief accounts of two cyclonic storms which occurred in the Bay of Bengal 150 years ago, extracted from Orme's History of India, will enable the reader to realize the dangers which sailors occasionally encountered in former days in the Bay of Bengal :—

"On the 2nd of October 1746 the weather at Madras was remarkably fine and moderate all day. About midnight a furious storm arose, and continued

with the greatest violence until the noon of the next day. Six of the French ships were in the road when the storm began, and not one of them was seen at daybreak. One put before the wind and was driven so much to the southward that she was not able to gain the coast again; the 70-gun ship lost all her masts; three others of the squadron were likewise dismasted, and had so much water in the hold that the people on board expected every minute to perish, notwithstanding they had thrown overboard all the cannon of the lower tier; the other ship, during the few moments of the whirlwind which happened in the most furious part of the storm, was covered by the waves, and foundered in an instant and only six of the crew escaped alive. Twenty other vessels, belonging to different nations, were either driven on shore or perished at sea. Two ships, laden with part of the effects of Madras, together with three lately arrived from Europe, were at anchor in the road of Pondicherry, where they felt no effect of the storm which was raging at Madras."

"In the evening of the 13th of April 1749 the northern monsoon changed, and the southern commenced with a hurricane on the Coromandel Coast. At Portonovo it lasted with such violence until four o'clock the next morning that the tents of the English forces which were encamped on the bank of the River Vellar (which disembogues itself at Portonovo) were blown into rags, many of the draught bullocks and horses were killed, and all the military stores were so much damaged that the army was obliged to march to Portonovo, in order to repair the detriments it had sustained. Here they were informed that the storm had committed much greater ravages at sea; two of the Company's ships were stranded between Cuddalore and Fort Saint David; the *Apollo* hospital ship was lost with all her crew; the *Pembroke*, a 60-gun ship, which sailed on the expedition, was wrecked and only six of the crew saved; and the *Hamur* of 74 guns, in which Admiral Boscawen hoisted his flag, and which was the finest ship of her size belonging to the navy of England, perished with 750 men. Fortunately most of the other ships were either at Trincomalee, or in parts of the coast to which the greatest violence of the hurricane did not extend."

It is hardly too much to say that the knowledge of the laws of storms, which is due to the labours of meteorologists utilizing the observations furnished by thousands of seamen, is now sufficient, if properly employed, to enable sailors to avoid the full strength of cyclonic storms in the open sea of the Bay of Bengal. Disasters still occasionally happen, and, in some cases at least, may be traced to neglect of the most ordinary precautions, or to disregard of the accumulated experience of the past. The following are the most noteworthy disasters which have occurred in the Indian seas during the past fifteen years. During a cyclonic storm in the Arabian Sea and Gulf of Aden in May 1885, the *Augusta* German man-of-war, the *Renard* French man-of-war, and the S. S. *Speke Hall* foundered at sea, within a few hours of each other. In May 1887 the steamer *Sir John Lawrence*, with upwards of 800 pilgrims for Puri on

board, foundered in a cyclonic storm on her passage from Calcutta to Chandbali. In June 1887 the steamer *Lamport* left Bombay Harbour during stormy weather in the Arabian Sea and foundered at sea. In November 1888 the coasting steamer *Vaitarna*, with several hundreds of native passengers, went down off the coast of Kathiawar during a cyclonic storm in the Arabian Sea. In the Port Blair cyclone of November 1891, the Government steamer *Enterprise* was wrecked outside the Port Blair harbour, the whole of the crew being lost with the exception of six lascars and the pilot vessel *Coleroon* foundered near the Orissa Coast with all hands.

These examples are sufficient to show that well-appointed ocean steamers and coasting steamers under the command of masters who had many years' experience of the storms of the seas they were navigating have foundered during recent cyclonic storms in the Indian seas. The dangers are hence as great and real now as they were a hundred and fifty years ago, when much less was known of their character, and it is only by the exercise of prudent caution and the employment of the accumulated experience of the past formulated in what is now commonly called "the laws of storms" that sailors will be able to avoid the worst dangers of these storms.

The chief object of this work is hence to state the laws of the formation, development, and tracks of storms in the Bay of Bengal, so far as they are at present known, mainly from observations furnished by sailors.

Arrangement of subjects.—The subject is treated under the following heads :—

(1) Explanation of meteorological ideas and phrases and of some of the more important principles of the science and description of the instruments employed for meteorological observation and of the methods of observation.

(2) Brief description of the normal weather and currents in the Bay of Bengal, month by month, throughout the year.

(3) Description of the chief phenomena of cyclonic storms in the Bay of Bengal, and explanation of methods of ascertaining the existence, position, and tracks of cyclonic storms.

(4) Brief account of eight of the most important and typical storms in the Bay of Bengal during the past 35 years.

(5) Summary, giving brief practical hints respecting storms for the use of sailors navigating the Bay of Bengal.

CHAPTER I.

EXPLANATION OF METEOROLOGICAL PHRASES AND PRINCIPLES.

Before commencing the subject of this volume, *viz.*, cyclones, it appears to be desirable to give a brief explanation of those properties of air which are of

importance in meteorology, and of the chief technical terms made use of by all who study the weather at the present time, and also of some of the more important results of meteorological observation in India and the adjacent seas with which the sailor should be acquainted if he is to draw the utmost advantage from the rules laid down in Chapters I and III.

Necessity of technical terms.—No class of men know better than sailors the necessity and value of technical language, as they employ it perhaps to a larger extent than any other class of men. The following extracts from a very interesting work called "Sailors' Language," by Clark Russell, state this in a very striking manner: "Sailors' talk is a dialect as distinct from ordinary English as Hindustani is, or Chinese. English words are used, but their signification is utterly remote from the meaning they have in shore parlance. A yard ashore means a bit of ground at the back of a house; at sea it is a spar. Every cabman knows what a whip is; but at sea it is a tackle formed by a single rope rove through a block. A traveller ashore is a well-known individual; but at sea he becomes an iron ring fitted so as to slip up and down a rope. A lizard is not a reptile, but a bit of rope with an iron thimble spliced into it, just as a bull is a small keg, and bees pieces of plank at the outer end of the bowsprit. Beating is not striking, but sailing by tacks; a bonnet is not for ladies' wear, but a piece of canvas laced to the foot of a jib; whilst a cat's-paw has as little to do with the feline animal as fiddles and harpings have with music." And "of many sea-phrases the meaning is really so subtle as utterly to defy translation, whilst many fit the vocational conditions so accurately that any divergence from the exact expression will puzzle a seaman as much as if he was being ordered about in French. There are shades of signification in the terms which a man must go to sea as a sailor to understand. No books will give them. They are not to be mastered by listening to seamen talking." "Any way, it is quite certain that to stop a sailor from telling his story in his own fashion is, to use his phrase, 'to bring him up with a round turn,' and to expect him to find other words than those which occur naturally to him in relating incidents of a profession crowded with expressions to be heard nowhere except on board ship, is to put him upon a labour of definitions which even a Samuel Johnson would, I suspect, very promptly decline."

Hence sailors at least will excuse, even if they do not always appreciate, the two or three dozen technical terms such as *inertia*, *baric gradient*, *humidity*, etc., which meteorologists use for the sake of brevity and clearness. Technical language has the great advantage of being perfectly clear and definite to those who understand it. It is generally a little troublesome to acquire, but no one who has learnt it ever thinks of returning to the clumsy roundabout expressions which it replaced. Meteorologists have been obliged to employ a number of technical terms and expressions, and it is very desirable, if not absolutely necessary, that every one who wishes to make use of weather reports or publications

issued by meteorological offices should learn the meaning and use of those terms. It is therefore proposed in this chapter to state some of the chief properties of the air or atmosphere surrounding the earth, to explain the more important terms used by meteorologists in narrating and explaining weather changes, and more especially those violent changes termed storms, to describe the kinds of meteorological observations that can be usefully taken at sea for storm prevision and the instruments employed to take these observations.

Air has weight.—The air is an invisible substance, very light as compared with the same volume of ordinary solid matter, but, notwithstanding, having weight. This is of course very easily proved by weighing accurately a hollow stoppered bottle or vessel, first with air inside, and secondly, after the air has been pumped out by means of an air-pump. There is always found a slight difference between the two weighings, the difference representing the weight of the air which was inside the vessel in the first case.

The weight of any number of cubic feet of a gas or of air under the same conditions can be at once found by a simple multiplication sum when the weight of one cubic foot is known.

The chief difference between liquids and solids on the one hand and gases on the other is that while a cubic foot of a liquid or solid weighs practically the same under all ordinary circumstances, the weight of a cubic foot of air differs very greatly under different circumstances and may be as small a quantity as ever we please. This is due to the fact that gases possess the property of indefinite expansion as their pressure diminishes.

Method of calculating the weight of a quantity of air.—The weight of a cubic foot of dry air at rest near the earth's surface depends really upon two factors—its temperature and the amount of pressure to which it is subject. It is very rarely necessary in meteorology to know the weight in pounds or ounces of a cubic foot of air, but the following rules will enable any one to find it approximately in any given case.

The weight of a cubic foot of air at the pressure of 30 inches (that is, when the upper surface of the column of mercury in the tube of a barometer placed in the air stands at a height of 30 inches above the level of the mercury in the cistern), and at the temperature of freezing water (or 32° Fahr.) is 565 grains or 1·29 ounces. Seven thousand grains, it should be remembered, are exactly equivalent to one pound. If the air be kept at the same pressure (by allowing it to expand suitably), every degree rise of temperature diminishes the weight of a cubic foot by one grain very approximately. Thus, the weight of a cubic foot of air near the surface of the sea in the Bay of Bengal, when the barometer stands at 30·00 inches, and the temperature is 72° (or 40° higher than the freezing point), is 565 less 40, or 525 grains. When the weight of a cubic foot of air at the pressure 30 inches and at any temperature has been found, the weight of a cubic foot at any other pressure at the same temperature, can be at once found by a

rule-of-three sum, the principle being that the weight diminishes at the same rate as the pressure decreases. Thus, if the pressure diminishes from 30 inches to 29 inches or one inch out of 30, the weight will also diminish by $\frac{1}{30}$th, and so on. Thus, in the centre of the False Point Cyclone of September 1885, where the air was at the temperature 82° and the barometer stood at 27 inches nearly (or more exactly 27·13″), the weight of a cubic foot of air was only 464 grains, or 100 grains less than the weight of a cubic foot of air on a dry cold winter day in England. This follows at once from what has been said. The weight of a cubic foot of air at 30 inches pressure and temperature 82° (or 50° above the freezing point) is 565 grains less 50 grains, or 515 grains, and at 27 inches pressure, or 3 inches less than 30 inches (that is, a decrease of 1 in 10), the weight would be 515 less 51·5 grains (because 51·5 is the tenth part of 515), or 463·5 grains.[1]

Air has inertia.—The fact that the air is a heavy substance is one of much importance to the meteorologist from another point of view. If it be wished that a heavy body should move from rest or move more quickly, force must be applied to it, or work must be done upon it by some agent. Also, when a heavy body is in motion there are always resistances which oppose its motion, and tend to bring it to rest. Hence, if its motion is to continue unaltered for a considerable interval of time, work must be done upon it or energy given to it by some agent (usually some other portion of matter). The principles of work and energy appear to be more or less mysterious when stated in mathematical form. They are, however, comparatively simple, and are more or less fully acted on by every workman. Any sailor wishing to have a simple statement and explanation with numerous illustrations from every-day life is recommended to read Balfour Stewart's "Conservation of Energy." It will suffice to give one or two illustrations. A mason every time he lifts a hammer does work on the hammer, and at the same time he loses a small amount of energy, *i.e.*, that something which he possesses to a limited amount, and in virtue of which he can do a certain amount of work. The hammer when lifted up, although unchanged in appearance, has acquired some energy or power of doing work, and this is shown by the fact that if it be allowed to fall down on a piece of iron or stone, it will make some change in it. If properly directed during its fall by the workman, it will effect the change required, *e.g.*, break off the exact portion of stone desired and hence do useful work. If it be improperly directed, it will

[1] For any who can use a simple mathematical formula the weight of a cubic foot of air can be calculated approximately at ordinary temperatures from—

$$W = \frac{19p}{1 + \frac{t}{500}} = 19p\left(1 - \frac{t}{500}\right)$$

Where W is the weight in grains (of which 7,000 make a pound avoirdupois), p the pressure measured in inches of barometric height, and t the temperature above the freezing point in degrees Fahrenheit.

still fall and do work, *e.g.*, break off a portion of the stone, but it will probably not be useful work, *i.e.*, that which will be of use for the particular object the workman has in view. Similar principles apply in any other of the numberless cases which will occur to any one.

Work may perhaps be best defined as *the exercise of force by some portion of matter through a definite space in order to produce a change of the position, shape or motion of some other portion of matter. Energy is that property of matter by which it is enabled to do work of any kind.*

The principles of work and energy apply equally to the motion, &c., of matter in the gaseous form as to that of matter in the solid state. This is, from one point of view, usually expressed by stating that air, like solid or liquid masses of matter, has the property of inertia, that is, requires force (due to the action on it of some other mass of matter) to put it in motion, to maintain its motion unaltered against resistance, or to bring it to rest when in a state of motion. Exactly the same principles and the same methods of argument, for example, hold good for the motion of a mass of air as for the motion of a steamer or of a railway train. Coal, for example, is the agent in these cases. It contains before it is burnt a large amount of energy, which with proper arrangements it can give out to the mechanism of the steamer or train and the attached bodies. When the machinery begins to act, it causes the ship or train to move more quickly up to a certain limit. If its action be discontinued (*i.e.*, the steam be shut off from the engine), the steamer or train comes gradually to rest as its motion is resisted by the air, by friction with the water or rails, &c. If it be required to move at the same rate for some time, the engines must continue to be worked, otherwise, the body will gradually move more and more slowly and finally come to rest. One of the simplest, and yet most important, considerations for an engineer of a steamer, &c., is that the engines should be powerful enough to move the steamer, &c., at the greatest speed (10 or 12 miles per hour) that may be desired. It would be an absurd act of folly that no one would think of commiting to put engines intended for a small steam yacht into a 6,000-ton man-of-war steamer.

The sun is the great source of energy or the motive power acting directly or indirectly on the atmosphere.—It has been already stated that the air is like any other kind of matter, as, for example, a railway train, a cannon ball, or a piece of machinery, in that if it is at rest it cannot put itself in motion, or if moving it cannot of itself move more quickly, or if moving as it does in the open against resistances, work must be done upon it or energy communicated to it by some other portion of matter if it is to continue to move with undiminished velocity. Any change of motion of a mass of air can only be effected by some power or force (due to some other portion of matter) acting on it. This power or force may either act directly or indirectly through some connection (equivalent to a train of mechanism) transmitting the moving power

or energy. Hence one of the more important enquiries that any one studying the weather has to take up, is to find out what is the agent or motive power which supplies the energy that puts large masses of air into rapid motion and maintains the motion for considerable intervals of time. For example, in many of the larger cyclones of the Bay, a mass of air, 100 miles at least in diameter and probably not less than a mile in height, is caused to move at a rate which averages at least 40 (if not 60) miles per hour. The mass of air put into this rapid motion weighs as much as half a million 6,000-ton ships at the least and moves more than three times as quickly. It should also be remembered that this amount of motion has not only to be gradually given to the mass of air, but that it is frequently continued for several days against the various resistances offered to the moving mass of air. How effective and powerful these resistances may be in certain cases is shown by the fact that the Backergunj cyclone, one of the largest of the present century, was completely destroyed by the resistance of the hills of Eastern Bengal in the space of a few hours. The amount of power necessary to maintain this motion after it has been generated is difficult to estimate, but is certainly equal to the engine power that would be necessary to drive some hundreds of thousands of 6,000-ton steamers at the rate of 12 miles per hour. Whence is this power, this energy, derived? It is in trying to answer this question that many make the mistake of assigning an utterly inadequate and feeble cause to a vast and massive effect or result. Some, for example, suggest the electricity of thunder-storms, etc. It can, however, be shown, and has been proved conclusively, by Faraday and others, that the electricity set free in a violent thunder-storm would not have sufficient energy or power to drive an electrical tram-car half a mile, or produce more violent effects than a few pounds of dynamite. Others again believe that the moon is mainly responsible for the violent motion of large masses of air which form storms, and that when its illuminated face is turned full, or sideways, or in some other particular direction, it is much more powerful and influential than at other times.

The force of the sun upon the whole earth or upon any body or mass of matter of any kind at or near the earth's surface is 140 times as great as that of the moon on the same body. The common statement that the earth moves round the sun and not round the moon is the ordinary and less definite way of expressing the same fact. Hence, under similar circumstances, the sun will be able to do by its mere pull, or attracting force, on the earth or any mass connected with the earth through a given distance 140 times as much work or produce 140 times as great an effect as the moon acting through the same distance.

This statement, it may perhaps be desirable to add, is quite compatible with the fact that the tide-producing power of the moon on the oceanic waters of the earth is considerably greater than that of the sun. The tides, it may be sufficient to state, are due to the fact that the moon and sun attract the waters of the

earth at different portions of its surface with different amounts of force according as these portions are near or further away. It is hence quite easy to see generally that a moderate-sized body like the moon at a comparatively small distance may produce a greater difference of effects at different parts of the earth than the larger body, the sun, which is at a very much greater distance. For a similar reason a bar magnet placed at a small distance from a magnetic needle tends to pull it away as well as to turn it round, whilst the earth, an immense magnetic body, exercises practically no pull on the magnetic needle though it turns it or directs it into a certain fixed position.

There is a second way in which the sun is exceedingly more effective and powerful than the moon.

The sun is an enormous reservoir of heat which it is giving out continuously. The heat thus radiated is propagated through space, and produces at the surfaces and in the atmospheres of the planets all the changes that heat is capable of effecting. The moon, on the other hand, is a cold body which scatters a little of the heat it receives from the sun into space. This is, however, so small in amount that the most delicate instruments are required to measure it.

The following results of calculation will perhaps put the matter more strongly and clearly. The amount of the sun's heat received by the moon is only about one thirty-thousand millionth part ($\frac{1}{30,000,000,000}$) of the whole heat given out by the sun. Hence, as a centre of communicating heat, (assuming that it gives out all the heat it receives from the sun), it can be shown by calculation that the moon would produce less than one two-hundred-thousandth part ($\frac{1}{200,000}$) of the heating effect on the earth that the sun does directly. For example, if we assumed that the sun in a given time was able to melt a thickness of four miles of ice at the earth's surface, the moon could not possibly melt more than about an inch in the same time.

It is hence evident that whether we consider the moon as an attracting body or as a source of heat, its energy or power is exceedingly small, compared with that of the sun. The total action of the moon on the atmosphere, which is chiefly influenced by heat, bears about the same relation to that of the sun as a molehill to a mountain. To refer these large and violent atmospheric disturbances called storms to the moon—a feeble cold mass—is to say the least, to assign an utterly inadequate and feeble cause to a very large and massive effect. Meteorologists hence almost universally assume that the sun is directly or indirectly the agent or the motive power, which produces all the larger changes or motions in the earth's atmosphere. It is its energy alone which maintains the steady Trade-winds from year to year and the periodic monsoon winds of India, and which sets in motion those fierce destructive hurricanes or cyclones of the Indian and Atlantic Oceans that are the dread of the sailor.

Air motion.—We have thus seen that the air is a heavy substance, and that

in order to put large masses of it into rapid motion, and more especially to originate the enormous motion of a large cyclonic storm, the expenditure of a vast amount of power is necessary and that this power or energy is derived ultimately from the sun.

Character of air motion on large scale.—There are certain peculiarities in air motion which it is desirable to explain. The atmosphere forms a continuous mass surrounding the earth, which has a lower surface, because it rests against the earth's surface, but which almost certainly has no upper surface like that of the waters of the ocean, so that there is in the atmosphere nothing akin to the waves of the oceanic waters.

Hence, when there is prolonged motion in such a mass as the open air, if we consider the onward motion of any portion, it is evident that the air in front of that portion must be also moving onwards and vacating the space to be filled by the advancing air, and also that the air behind the advancing portion will move forwards to fill up the space vacated. Hence the motion of air at any point also necessarily implies that the air is moving in front and behind. And the same will be true for these two portions of air in front and rear, and so on. The same argument continued will show that the only prolonged air-motion possible is one which returns finally into itself or motion in a circuit or closed path.

Air motion is chiefly circulation.—It resembles to some degree the motion of a continuous band such as is used for driving machinery or that of the electrical current (as it is usually considered) in a continuous wire. When the air is moving on the large scale it is hence in all cases moving more or less in a circuit. Thus, in the case of the Trade-winds the air moves over the earth's surface for some considerable distance from the Tropics to the Equator (roughly speaking) ; then rises up over the equatorial regions, and turns at a considerable distance above the earth's surface and moves in the upper regions of the atmosphere in a direction opposite to that near the earth's surface and then descends to the earth's surface again near the Tropics. *The simplest term for the whole motion in such a circuit is circulation.*

The North-East and South-East Trade-winds form parts of such a motion or circulation. Such a complete motion as that of which the two Trade-winds form the lower portions may be represented as in the following diagram :—

FIG. 1.

North-East Trades. Equator. South-East Trades.

Winds which form part of such circulations as the above are usually steady winds which either prevail always, as, for example, the Trade-winds, or else for a

definite portion of the year, as the north-east and the south-west monsoon winds of the Bay of Bengal and Arabian Sea. They are rarely violent, and are never as a rule in their ordinary state stormy winds. The average force of the South-East Trade-winds in the Indian Ocean and of the monsoon winds in the Bay of Bengal varies from 3 to 5, as measured by the Beaufort scale, in which a calm is denoted by 0, and hurricane winds by 12.

It is also interesting to note that the rain given by such a circulation falls most largely in the area over which the air is ascending, and that very little rain falls over the area where the air is descending. This is the chief reason of the heavy rainfall in the Doldrums or Belt of Calms near the Equator and of the remarkable deficiency of rainfall near the Tropic of Cancer in Africa and Asia. It also helps to explain the comparative absence of rain and dryness of the air in Northern India during the cold weather or north-east monsoon, as the air is then descending over it and moving southwards in the Bay, and of the abundant rainfall over nearly the whole of Northern and Central India in the south-west monsoon. For the southerly surface winds of the Bay of Bengal and Arabian Sea at that season pass into Northern India and rise up or are continued as an ascending current over Northern India.

Air motion of expansion and contraction.—Another kind of motion of air that may occur is such as happens when a hollow ball of thin India-rubber, &c., is held near a fire. The air inside is heated and the elastic and flexible cover is driven slightly outwards, so that the air inside occupies a slightly larger volume than before. In ordinary language the air expands and motion of some kind is necessary to expansion. The motion, however, of the air in this case is quite different to that which would occur if the bladder were to burst. Any portion of air out in the open is in reality surrounded by a wall of air which, like the membrane of the ball, can be thrust outwards by the expansive action of the air within it when heated, so that the given portion of air occupies a larger volume than when it was colder. This takes place as a necessary result of heating. There is no doubt that this motion of expansion by heating and therefore also of contraction by cooling occurs on a large scale in nature. It is very probable, if not quite certain, that one of the daily effects of the sun's heat is to cause an upward expansional motion of this kind (with perhaps slight horizontal movement, especially between sea and land and between plains and mountains) which is followed by contraction at night as the air cools down again. The expansion is of course due to, and accompanies, changes of pressure. Where the action of the sun is large and regular, as in the tropical regions, the motion goes on with great regularity from day to day, and gives rise to the very uniform changes in the height of the barometer known as the diurnal tides or diurnal oscillation of the barometer. These evidently are in no way due to the double action of the sun and moon as in the case of the ordinary ocean tides. They have no such variation as that of neap and spring tides, and they occur at almost

equal intervals determined by the sun's apparent period of revolution round the earth, and not by the moon's. This, it may be added, is another strong proof that the moon practically exerts no power or influence on the atmosphere of the earth.

It should perhaps be noted that the expansive motion of the air, or the upward or downward motion of the air, is usually very feeble, and is never called a wind. Winds are movements of the air parallel to the earth's surface.

Motion of small masses of air through the atmosphere, such as perhaps occurs in squalls, nor'westers, dust-storms, &c.—Another way in which it is possible that a mass of air may move may be compared to that of a cannon ball. The given mass of air may be, from some cause or other (perhaps suddenly or impulsively), set in violent motion and force its way through the almost quiescent air in front of it driving it aside whilst the air closes up again behind it. There are some reasons for believing that the dust-storms in Upper India and the brief wind-squalls which occasionally occur at sea during cyclonic storms may be partly, if not entirely, motion of this kind.

Hence we see that so far as we have considered the subject of air motion in its simpler aspects, the motion of large bodies of air may be either—

(i) The slight motion accompanying expansion or contraction due to heating or cooling of the mass of air.

(ii) The onward motion of a mass of air which has been put into rapid motion, and forces or ploughs its way unbroken through a stagnant or comparatively slow moving mass of air.

(iii) Motion of large masses of air in a circuit or circulation. This may be—

(*a*) simple, as in the case of the Trade-winds,

(*b*) complex, as in the case of cyclones or when the motion is usually termed vorticose, which case remains yet to be considered.

There may also be any combination of the above motions. This frequently happens in the cases of No. ii and No. iii (*b*).

The most important case of combination of the above motions is that which occurs in all cyclonic storms.

Air motion in cyclonic storms.—This complex form of motion arises when more or less violent actions occur over an area or centre of disturbance. Thus, for example, when a very large forest is on fire, the heated air over it rises and the air flows in towards it from all sides. The air which rises up after it reaches a certain height tends to spread out and to move away in all directions. For reasons which are partly explained below, the inflow near the surface of the earth to the heated air does not take place directly, but by a species of spiral or revolving motion, forming whirls, such as are very common in

water motion, even on the smallest scale. The air is in such a motion drawn in to the centre, but not directly. It moves round the centre of the disturbance and at the same time moves towards the central area into which it is drawn and passes upwards. Hence, when such a disturbance is started, the air at and near the earth's surface rushes towards the centre from all directions, and the actual motion which results from such a rush towards a central area of disturbance and uptake is always rotatory. In the case of very small whirls such as give rise to waterspouts at sea, the whirling or rotatory motion is probably due to the fact that the air from different directions rushes in with slightly different velocities or rates of motion. In the case of the enormous whirls which form cyclonic storms this is not the chief cause in operation. This is due to the fact that the air is connected with the earth, which is a moving body. Hence, when the air is in apparent motion, it is actually moving with respect to a body which is itself in motion.

This introduces an important action which was only brought into full notice some years ago. Before stating it, it will perhaps be better to give an illustration. Suppose a person sitting or walking about in a train moving rapidly and that the motion of the train is suddenly altered by coming in collision with another train. The man would be by this change of motion suddenly thrown forward, and the effect, so far as the man in the carriage is concerned, is just the same as if he were impelled forward by a powerful force. This is only a particular case of a general principle. If two bodies are connected and moving with respect to each other, any change in the motion of the one will produce an effect on the other, which will be equivalent to the action of a force, and which may be most simply explained by assuming the existence of this equivalent force.

It is also evident that if the change is sudden, the equivalent force will be a sudden force, almost like a blow, whilst if it is gradual and continuous the force will be of the same character. Now, air, when it is moving over the earth's surface, is connected with, and moving with respect to, a body itself in motion. And, so far as one part of the earth's motion is concerned, *viz.*, the motion round its axis once a day, the rate of motion differs at different parts of the earth's surface, being greatest at the Equator and diminishing to nothing at the Poles. It can be shown mathematically that the effect of the air moving over the earth's surface is almost exactly equivalent to the supposition that the earth is at rest and that there is a force which is always (in whatever direction the air may be moving) tending to turn it in the Northern Hemisphere to the right hand of its line of motion. Thus it is that the air moving northwards from the Equator up the Bay of Bengal or Arabian Sea in the open sea is bent more and more to the right hand or east, and hence that the wind direction in passing northwards from the Equator up the Arabian Sea during the south-west monsoon changes from south through south-west to west-south-west. This is of course only out on the open sea, where there are no obstructions to modify this course.

Hence, if any disturbance arises in the air which tends to draw the air in from all directions, the air which moves directly towards it from all quarters will be drawn aside and have its direction continuously changed as it advances towards the centre, and from whatever direction it will be deflected towards the right hand.

It is not possible to represent such a motion by a single diagram. In a vertical section through the centre the motion would be somewhat as follows :—

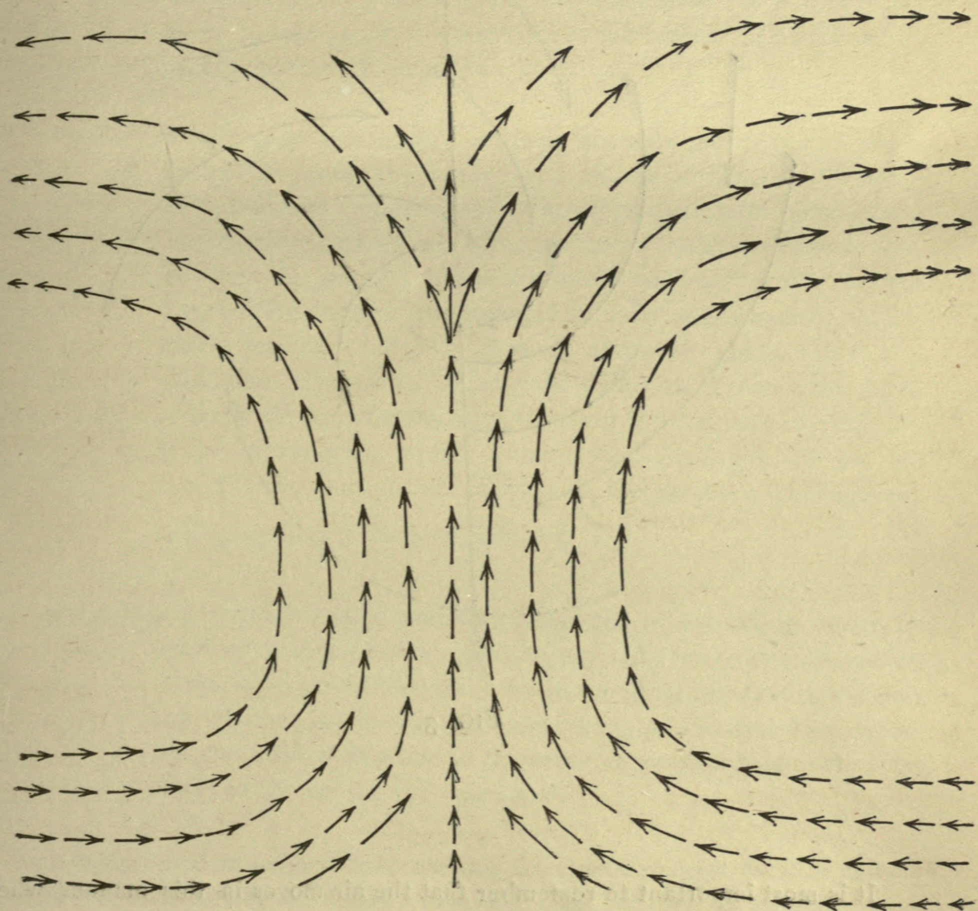


FIG. 2.

This, however, represents one feature of the motion and by no means the most important part. The air is drawn into the centre, but is not drawn directly to it. The particles move by a kind of spiral path to the centre figured as below, and hence tend to carry bodies inwards by such a path—

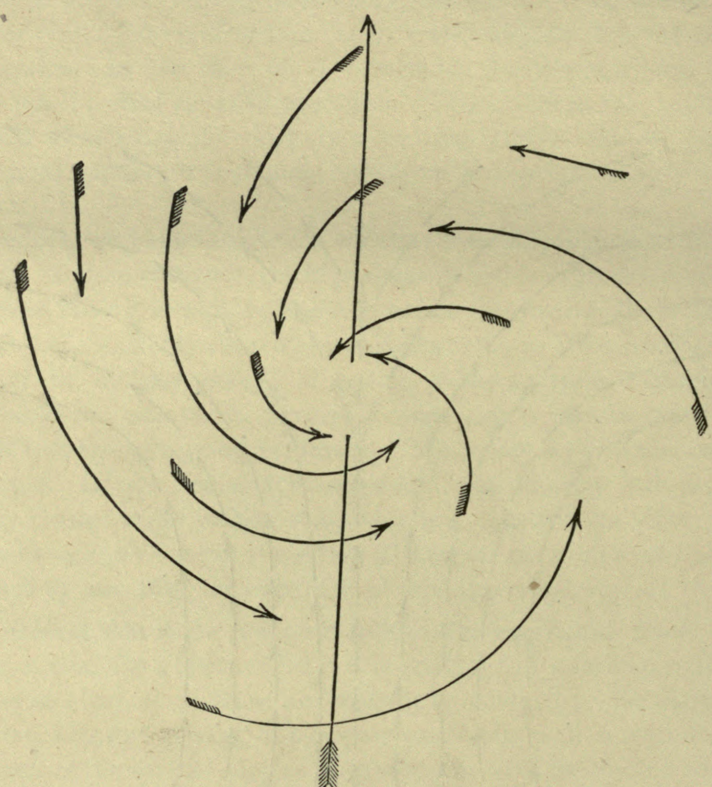


FIG. 3.

It is most important to remember that the air moves in this manner when there is a central disturbance giving rise to a rapid motion of the wind about the centre and of indraught towards the centre. It has been stated by several of the older meteorologists that the air moves round the centre in a circle as a point on the rim of a wheel moves round the axle, and that, therefore the direction of motion of the wind is at right angles to the direction, or bearing, of

the centre. Every cyclonic storm that is investigated, in whatever part of the world it occurs, furnishes fresh evidence of the error of Piddington, Reid, and others on this point and confirms the spiral theory of the motion of the air in cyclones. Such a motion of the air is called a cyclonic circulation and *may be very feeble, or it may be so violent as to constitute a dangerous storm.*

Cyclonic circulations have certain general features, the chief of which should be carefully remembered :—

1st.—The barometer is always low at or near the centre, and is high on the outskirts, or outer edge, of the circulation, and diminishes as we proceed from the outskirts to the centre. The fall is also usually most rapid near the centre.

2nd.—The air near the earth's surface not only moves round, but is drawn in towards the centre and moves always in the same direction with respect to the centre in the northern hemisphere. The air moves round in a direction which is the opposite to that in which the pointers of a watch move, so that, roughly speaking, to the east of the centre southerly winds prevail, to the north, easterly winds, to the west, northerly winds, and to the south, westerly winds. Hence the direction of the wind in a cyclonic storm indicates to an observer in what part or quadrant of the storm area he is. This motion is usually known as the cyclonic motion of the wind in the northern hemisphere, and is frequently denoted thus— $\circlearrowleft$

3rd—At and near the centre over which the air is ascending there is much development of cloud, and frequently heavy rainfall, whilst in the outskirts, where there are descending currents, fine clear dry weather is the rule, and there is a gradual transition from the one kind of weather to the other as we pass from the outskirts to the centre and *vice versâ.*

The readers should hence remember that to a meteorologist what is called a barometric depression, or a low, over an area relative to neighbouring districts and a cyclonic circulation are similar terms and suggest the same kind of air motion or disturbance. If the motion be violent, it of course forms what may be termed a cyclonic storm or cyclone, and if excessively violent, a hurricane.

The following are three examples of cyclonic circulation from the ordinary observations in India itself :—

The first gives the air motion in Bengal on the 27th May 1886 at 10 A.M., when the Balasore cyclone was passing northwards into Bihar. The winds are deduced from land observations where there is no difficulty in obtaining accurate measurements of their directions. The chart shows the incurving of the winds most strikingly, and is such as always occurs in a cyclonic storm in its passage over land in India—

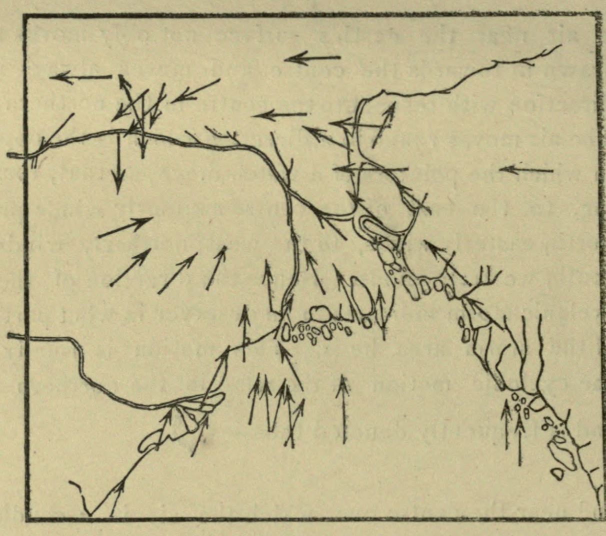


FIG. 4.

The next case gives the winds as actually recorded in the Bay of Bengal and at the coast stations on the 7th of November 1886, when a cyclonic storm was approaching the Madras coast. A very noticeable feature in this cyclonic circulation is the north-easterly winds on the coast of the Circars and Ganjam,

where easterly winds would be expected. This is an example of a peculiarity which will be referred to later on more fully—

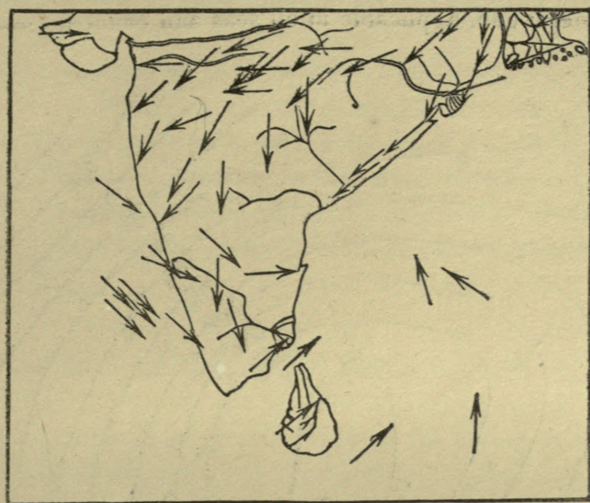


FIG. 5.

The third is a case of cyclonic circulation in India, but which was not attended with strong winds or squally weather. It is a chart showing the ordinary weather conditions in Bengal on dry hot days in April and May. In this case the isobars as well as the wind directions are given. The chart shows the incurvature of the winds to an area of slightly deficient pressure as markedly as in the preceding cases—

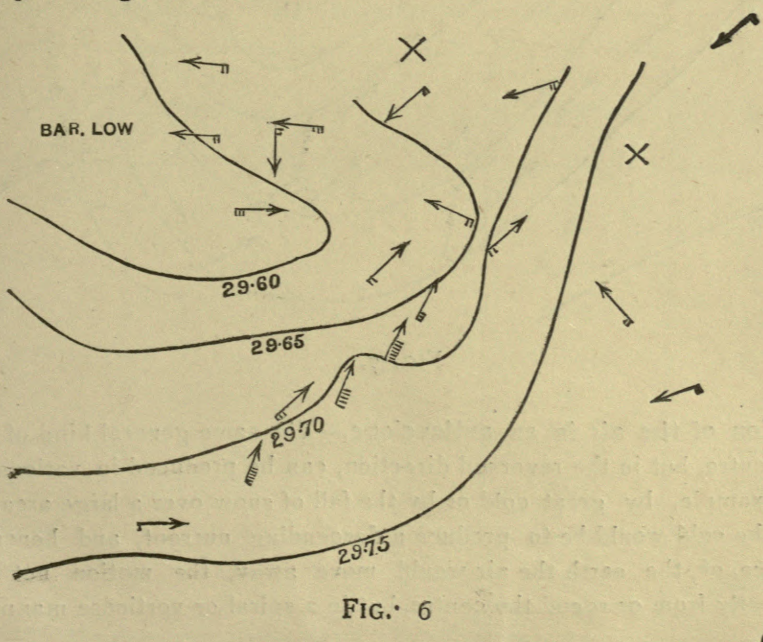


FIG. 6

The following case is given of a cyclonic circulation and storm passing across the United States in America, as it shows even more strikingly than the cases already given the incurvature of the winds, and further illustrates that the principle is a general one, applicable in all seas and countries :—

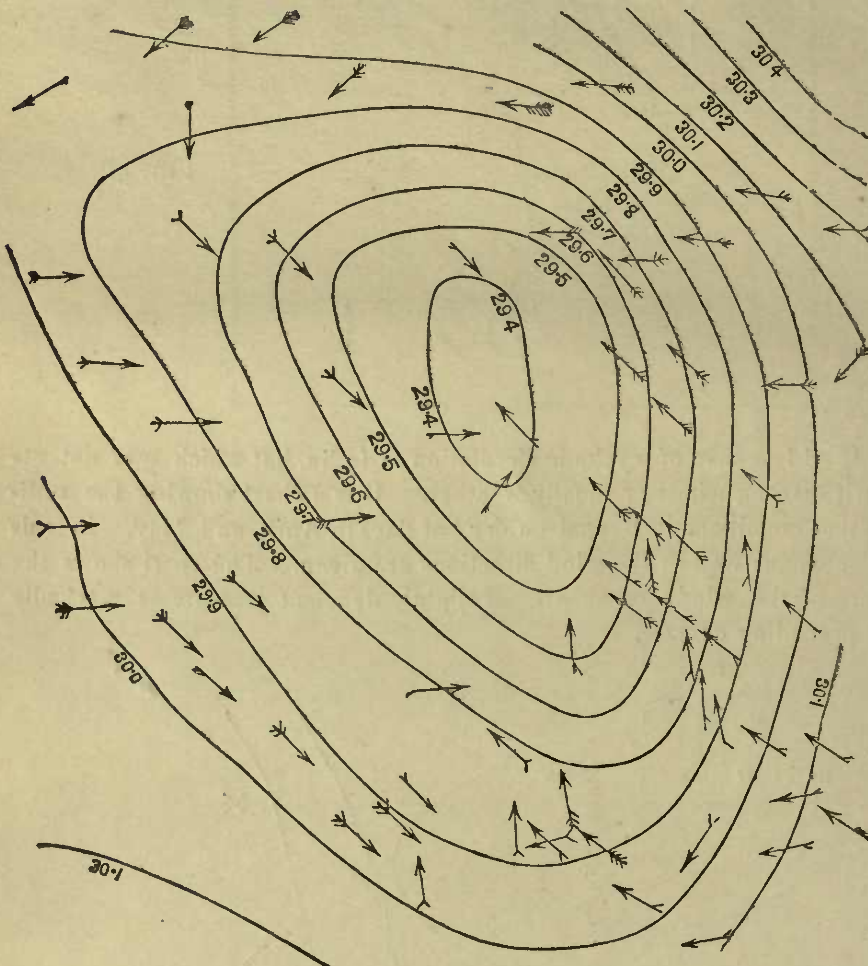


FIG. 7.

Motion of the air in an anticyclone.—The same general kind of motion about a centre, but in the reversed direction, can be produced in various ways, as, for example, by great cold or by the fall of snow over a large area. The effect of the cold would be to produce a descending current, and hence near the surface of the earth the air would move away, the motion not taking place directly from or round the centre, but in a spiral or vorticose manner, and

above the air would stream in by a similar kind of path to feed the descending current.

The chief features of such a motion are the opposite of those of a cyclonic circulation.

1st.—The barometer is highest near the centre and gradually falls as we pass from the centre outwards.

2nd.—The spiral motion of the air about the centre is performed in the opposite direction to that already described, or, in other words, the air moves round in the same sense or direction as the hands of a watch. The direction is usually shewn in the following manner:— ↻

Such a motion of the air is termed anticyclonic and the whole phenomenon an anticyclone. The motion of the air in an anticyclone is very rarely violent and never so in tropical seas, and hence it is not necessary for a sailor to study the relations between the wind directions and the centre of an anticyclone, if he is merely anxious to know sufficient to enable him to take the precautions necessary to enable him to avoid danger when he is involved in a storm.

Wind.—As the direction of the centre of a cyclonic storm is chiefly determined by means of the direction of the wind and its changes, it is very important that sailors should estimate it as carefully and exactly as possible.

The direction of the wind is recorded according to the points of the compass; at the land observatories in India it is estimated according to the following sixteen compass-points, which are found to be sufficient:—

Name.	Symbol.	Arc.
North	N.	0°
North-north-east	N.-N.-E.	22° 30′
North-east	N.-E.	45°
East-north-east	E.-N.-E.	67° 30′
East	E.	90°
East-south-east	E.-S.-E.	112° 30′
South-east	S.-E.	135°
South-south-east	S.-S.-E.	157° 30′
South	S.	180°

Name.	Symbol.	Arc.
South-south-west	S.-S.-W.	202° 30′
South-west	S.-W.	225°
West-south-west	W.-S.-W.	247° 30′
West	W.	270°
West-north-west	W.-N.-W.	292° 30′
North-west	N.-W.	315°
North-north-west	N.-N.-W.	337° 30′
Calm	C.	

In the case of land observatories it is determined by means of a wind vane, which has been carefully fixed in position, so that the direction is correctly given by the indications of the instrument. In the case of a ship at sea, this is not possible, as a wind vane would not give the actual wind direction, but the apparent wind direction as observed by a moving body, which is of course different from the former by an amount dependent on the speed and direction of motion of the vessel.

It is very important that sailors should determine the direction of the wind to the true north. There is little doubt that the directions as given in the logs of vessels are frequently erroneous, more especially those taken during cyclonic storms, from no allowance being made for the deviation of the compass due to the heeling of the vessel.

It may also be here noted that on land the direction of the wind is very considerably modified by the inequalities of the surface which obstructs the free motion of the air. Out on the open sea the wind directions observed in cyclonic storms are due to the cyclonic circulation undisturbed by other actions. Near the head of the Bay, more especially in the north-west of the Bay, the wind is affected to a very considerable extent by the proximity of the land, more especially in the outskirts of cyclonic storms where the winds are comparatively feeble. It is probably in part due to this that the wind in the north-west angle of the Bay hangs so long at N.-E. on the approach of cyclonic storms.

The only method in general use of measuring wind force at sea is by estimation. It is somewhat rough, but the general agreement of the wind observations contained in the logs which have been sent in to the India Meteorological Office indicates that it is much less dependent on the individual observer

than might at first sight be supposed, and that, as employed by sailors, it gives consistent and valuable results. The scale generally adopted by sailors is that devised by Sir F. Beaufort when in command of Her Majesty's ship *Woolwich*, and is based upon the pressure exercised by the wind on the sails of a ship. It is, on the whole, the best that has as yet been suggested, and has also the additional merit of being in general use on board English ships. It is as follows:—

Scale.

Number used to denote force of wind.	Character of wind.			Velocity of wind in miles per hour.
0	Calm			0 to 3
1	Light air, just sufficient to give steerage way			8
2	Light breeze .	or that in which a well-conditioned man-of-war with all sail set, and clean full would go in smooth water from	1-2 knots . .	13
3	Gentle breeze .		3-4 " . .	18
4	Moderate breeze		5-6 " . .	23
5	Fresh breeze .	or that in which she could just carry in chase	Royals, etc. . .	28
6	Strong breeze .		Single-reefed topsails or topgallant sails.	34
7	Moderate gale .		Double-reefed top-sails, etc.	40
8	Fresh gale .		Triple-reefed topsails.	48
9	Strong gale .		Close-reefed top-sails and courses.	56
10	Whole gale, or that in which she could scarcely bear close-reefed main topsail and reefed foresail			65
11	Storm, or that which would reduce her to storm-staysails . .			75
12	Hurricane, or that which no canvas can withstand			90 and upwards.

The velocities given in the last column have been determined in the English Meteorological Office.

The following remarks respecting wind observations on board ship are taken from the paper on "The Value of Meteorological Observations at Sea" read before the Shipmasters' Society already quoted (*vide* page 2):—

"Erroneous records of the direction and force of the wind may be made—particularly on board of a steamer under way—if the effect of aberration resulting from the progressive motion of the vessel be not taken into account. For instance, on any vessel running right before a strong breeze (Force 6) and progressing at the rate of 12 knots per hour, the apparent wind will be a moderate breeze. On any vessel moving ahead with the wind on beam of quarter, the apparent direction will make a larger angle with the fore and aft line of the ship

--computed from aft—than the actual direction, in other words, it will be further forward, and this discrepancy will increase as the speed of the ship increases, while the force of the wind remains constant, but will decrease with the freshening of the wind, provided the speed of the vessel remains the same."

"On board of a steamer going 13 knots with a light breeze (Force 2) right aft, there will be a calm. Conversely, in a calm, a steamer going 13 knots will induce a light breeze. A steamer steering east, progressing at the rate of 8 knots, with a light air (Force 1), freshening at times to a light breeze (Force 2) veering and backing between west by north and west by south, two points only, will appear to have the wind during the watch 'all round the compass,' as the saying is, although the wind will not have been unusually variable. *The direction of the sea, be it remembered—not of the swell—will be the direction of the wind and, excepting on a dark night, this fact can be made use of.*"

"In ascertaining the direction of the wind, I have always followed the plan described above; in fact, it seems to me that it is the only one that can be adopted on board a steamer. There are some tables in existence by which, the compass direction of the wind having been taken from a dog-vane or the smoke of the funnel, the true wind can be ascertained, but they are too troublesome for constant use on board ship, and I do not think any one would care to use them when taking observations twelve times a day."*

Relation between wind and pressure.—It has been already pointed out that even in the finest weather the barometer at the sea-level not only varies in height from day to day and from hour to hour at the same place, but also varies from place to place at the same instant. It is also found, more especially in tropical regions, that the barometer varies fairly regularly in going from place to place at the same instant. Hence it is that at the same hour the barometer is low in certain districts and high in others. An area in which the barometer (reduced to sea-level) stands at a lower level than in neighbouring districts is called an area of barometric depression or an area of depression. The weather charts published by India and other Meteorological Departments give special prominence to areas of depression, for stormy weather is invariably found in such areas. These depressions may be of small extent and amount or they may be large. It is, however, most important to remember that all such depressions, however they may differ in size and intensity, have certain features in common. These have been already stated in connection with air motion, but it is desirable to re-state them. In such an area it is found that pressure diminishes with approximate regularity from the outside of such an area to some point within it. This point is conveniently called *the centre of the depression.* It is also found that in such an area the air moves in a rotatory manner in such a way that it is not only moving round the centre but also is drawn into it, or in fact that the air motion in such an area always forms

* An explanation of a method for the determination of the true wind by mathematical methods will be found in Lecky's "Wrinkles in Practical Navigation," Chapter XIX.

a cyclonic circulation. Such areas of low barometer or barometric depression are not permanent. They commence to form and increase for some time in size and intensity, at the same time that they usually appear to advance in some direction, just as a temporary whirl in a stream of water moves for some time along with the stream and then disappears. After some time the barometer rises in the area, and the depression gradually fills up and disappears. *It should, hence, be carefully borne in mind that an area of barometric depression is necessarily an area of cyclonic circulation, and also that if the depression increases in amount and becomes large, the cyclonic circulation, which is at first feeble, becomes more and more vigorous and may gradually develop into a cyclonic storm or hurricane. Cyclonic storm areas are always areas of barometric depression and of cyclonic air circulation. A cyclonic circulation denotes a particular kind of air motion irrespective of whether the air motion is feeble, moderate or violent. A cyclonic storm, cyclone, hurricane, or typhoon is a rapid or violent cyclonic circulation of large extent.*

The preceding remarks have shown that in an area in which the barometer falls from the outside to a central point, the barometric depression is invariably associated with a particular kind of air motion. This is an example of a very important meteorological principle, *viz., that winds are strictly and closely related to changes of pressure.* It is hardly necessary to state that pressure plays exactly the same part with reference to air that slope or level does with respect to water. If the water stands at the same level everywhere, there will be no motion. If, on the other hand, there is a difference of level, and the water is free to move, it will at once commence to move from the higher to the lower level. Similarly, if at the level of the sea the barometer stood everywhere at the same height, or pressure were uniform, or unchanged, from place to place, the air would be at rest or in equilibrium. If, on the other hand, it diminishes from one district to another, it is always found that the air is in motion from the district of higher pressure towards the district of lowest pressure. If the pressure diminishes very slowly, the winds are found to be gentle, but if pressure diminishes quickly, the air moves rapidly. In fact, just as water moves more rapidly down a slope the steeper the descent, the more rapidly does air move as the pressure diminishes more rapidly with distance. Hence it is clear we want a term to express the rate at which pressure increases or diminishes from one point to another on the earth's surface. The term now used by all meteorologists is "*baric gradient.*"

Baric gradient.—The term "gradient" is very largely used in connection with railways. It is clear that a rise of 20 feet in one mile is twice as great a rise as a rise of 10 feet in a mile, and that a rise of 45 feet in one mile is five times as great a gradient as that of 9 feet in one mile. It is hence evident that a comparison of slopes or gradients is the same as that of two numbers (45 to 9 in the last case, and 20 to 10 in the former case) so long as the rise or fall

is given for the same distance, and this is what is usually done in estimating gradients.

In other words, when the rise or fall of level of a railway, etc., is calculated at so much per mile (or any other definite unit of length), it is termed the gradient, and the comparison of two gradients is simply that of two numbers and can be made without trouble and with hardly any calculation. It would, however, require a longish calculation to compare a rise of 15 feet in 1,194 feet with one of 365 feet in five miles and to ascertain which was the greater slope. The advantages of this practical method of comparing slopes or gradients are hence self-evident.

The term was so suggestive and enabled cetain comparisons to be made so easily that it was introduced into the language of meteorology many years ago. It has already been stated that whenever strongish winds are blowing differences of pressure obtain at the sea-level, and that the stronger the winds the larger are the pressure differences for the same horizontal distance. Hence the great principle that the strength of wind depends upon the differences of pressure. When the differences of pressure are stated for a given fixed distance, they are termed baric gradients. The fixed distance that was usually chosen until a few years ago was a geographical degree. For instance, if the difference of the height of the barometer at two places 7° apart be ·14″ or fourteen hundredths of an inch, the baric gradient according to that method of measurement would be $\frac{1}{7}$ of ·14″, or two hundredths, and so on. The units now selected and used by international agreement are respectively one hundredth of an inch of pressure, and fifteen geographical miles for distance. These are hence the units now employed in the India Meteorological Office for the measurement of baric gradient.*

The principle stated above may hence be expressed as follows:—*The direction and strength of the winds depend upon the direction and amount of the baric gradient or pressure slope. The baric gradient is the fall or rise of pressure in hundredths of an inch per quarter degree.*

The relation is somewhat complicated, and has been expressed more or less imperfectly in various mathematical formulæ. It will be sufficient for the sailor to state it roughly in words.

Relation between Wind Direction and Baric Gradients (Buys Ballot's Law).—The principle laid down in the preceding paragraph holds good universally, and the relation between the wind direction at any place during a cyclonic storm and the bearing of the centre on position of pressure to west, is only a particular case of the general principle. Professor Buys Ballot, of Utrecht,

* As it is as convenient to have a name for the unit of baric gradient as it is for the units of length, time, etc., I propose to use the term grad. One grad means a rise or fall of air pressure horizontally of ·01″ in a quarter degree or 15 geographical miles.

was the first in Europe to draw attention to its great importance, and stated the relation in a simple form as follows :—

"*In the Northern Hemisphere stand with your face to the wind and the barometer will be lower on your right hand than on your left.*"

"*In the Southern Hemisphere stand facing the wind and the barometer will be lower on your left hand than on your right.*"

These two principles are hence recognised as Buys Ballot's Law. By their employment we can tell, knowing the direction of the wind at any place, in which direction the barometer rises or falls, and if we know in which direction the barometer falls or rises most rapidly, we can at once state what wind is blowing at the place.

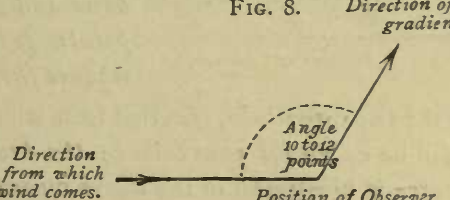
For example, suppose that northerly winds are blowing at the Sandheads. Looking northwards (to face the wind), Orissa is to the left and Arakan to the right. Hence pressure will decrease in going from the Sandheads eastward towards the Arakan coast, and increase in going westward towards the Orissa coast. And so on for other cases.

The relation as stated in the preceding law, or principle, is not definite enough in the case of the barometric depressions in which the air motion is strong or violent. The subject will be discussed more fully in the next chapter. The following statement will be sufficient for ordinary use.

Fuller statement of the relation between Baric Gradients and Wind Direction.—The relation between the baric gradients and winds may be stated as follows :—

Starting from any place the barometer will fall in a certain range of directions and rise in the remaining range of directions. There will be one direction of most rapid fall of the barometer which will be the steepest down-gradient. Suppose you stand so that this direction of the steepest gradient is to your right hand, then you will face the wind, which will come from a direction varying from 10 to 12 points from the direction of the sleepest gradient and its

FIG. 8.



strength will depend upon the magnitude of the gradient. If the gradient be small the wind will be of force 0 to 3, and will increase rapidly in strength with increase of gradient.

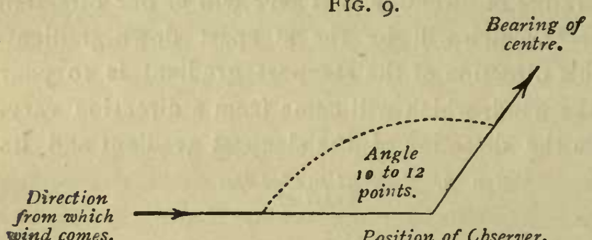
Thus, the gradients in the Bay are from north to south during the north-east monsoon and the pressure differences usually vary from one to one and a half hundredths of an inch per degree (equivalent to mean gradients of ·25 grad to ·37 grad). The winds are then from north-east and of force varying in ordi-

nary weather from 1 to 3. During the south-west monsoon (in July, August, and September) the steepest gradients *in ordinary weather* are from south to north, and the pressure differences are from two to three hundredths of an inch per degree (equivalent to mean gradients of ·50 grad to ·75 grad),—that is the ordinary gradient in the south-west monsoon is about twice that of the ordinary north-east monsoon, and the average force of the wind appears from logs to vary from 2 to 6, and averages about 4.

Gradients rarely exceed three or four hundredths of an inch per degree (or ·75 to 1 grad or unit of gradient according to the new notation) in the Bay of Bengal except within the area of a cyclonic storm. As the centre is approached, the gradients become steeper and steeper, and in the case of the most intense cyclones very steep gradients occur. The most remarkable and steepest gradients that have ever been observed in the Bay occurred during the False Point cyclone. The difference between the height of the barometer at a distance of about 35 miles from the centre and that at the centre, was upwards of two inches (2·4 inches), which is equivalent to 480 hundredths of an inch per geographical degree (or 120 hundredths of an inch per quarter degree or grads), or nearly two hundred times as steep as the ordinary gradient of the month in which the storm occurred in the Bay.

The most important application of these principles is in the case of cyclonic storms. The direction of the steepest gradients at any position in the storm area coincides closely with the direction, or bearing, of the centre. Hence, as a particular case of a perfectly general principle, is the following rule that is frequently given :—

FIG. 9.



To find the bearing of the storm centre at any position within a cyclonic storm, face the wind exactly, and the centre will be on your right hand and from ten to twelve points from the direction whence the wind comes.

This angle between the two directions, *viz.*, that from which the wind comes and that of the centre, will be called for convenience *the bearing angle.* The method of finding the centre is illustrated in the above diagram (Fig. 9).

This point will, however, be examined and discussed more fully in the third chapter and fuller rules given for the application of the principle to the determination of the bearing of the centre of cyclonic storms.

Measurement of air pressure.—The preceding remarks have shown the important part which the air pressure plays in meteorology. Its exact measurement is hence one of the primary elements of meteorological observation. It is usually effected by one or other of two classes of instrument, *viz.*, the

mercurial barometer or the aneroid barometer. A reference to either of these instruments will show that the measurement is in inches, that is in terms of a length. Pressure is not a length but a force. The direct measurement of the air pressure as a force is difficult to make and is hence rarely attempted. It is usually measured by the length of a column of mercury on the supposition that the weight of a given length of the column, say one inch, is invariable, so that for the comparison of air pressures as forces may be substituted, the comparison of lengths of a column of mercury of fixed characteristics, *i.e.*, of standard temperature and standard gravity. The mercurial and aneroid barometers are the most valuable and important meteorological instruments on board ship, and hence the greatest care should be taken to select the most suitable and trustworthy instruments and to learn to read them accurately and to utilize the observations or facts thus obtained in the best manner for guidance in all weathers, but more especially in stormy weather. The following paragraphs are devoted to these points.

The Barometer.—The barometer is the only meteorological instrument which is universally employed on board ship by mariners in judging of approaching stormy weather. It is also the chief instrument used in all meteorological observatories, and it is mainly by means of barometric observations transmitted by telegrams that the meteorologist in his office is enabled, not merely to follow the course and phases of a storm, but to issue useful and reliable forecasts and to hoist warning signals. Sailors, although they are more interested than any other class in accurate fore-knowledge of the weather, are occasionally inclined to neglect or despise the more exact methods of modern meteorologists, and to rely solely upon sky and weather indications.

The barometer is a simple scientific instrument or tool, and requires to be properly used to be of value. In the hands of an accurate and intelligent observer its indications are of the greatest value. It is employed for the purpose of finding the pressure of the air at the time and place of observation, and if properly utilized gives the observer certain and definite information from which to infer the present and probable future general character of the weather, so far as it can be determined by its use.

Necessity for the use of accurate and trustworthy barometers.—The first requisite for accurate and useful measurement is a good instrument. The sailor recognizes this most fully in the case of chronometers. He uses the best and most accurate he can procure. He is provided with, and employs, usually two or three, for he recognizes that human workmanship is never perfect, and that no chronometer will keep exact time, and that it is therefore desirable to have several to check each other, and thus enable him to obtain as accurately as is possible on a long voyage a determination of Greenwich time. He compares them at every available opportunity with standard clocks, time-ball signals, etc., and thus determines their errors and rates as frequently as he

can. In every calculation he makes to find his longitude he allows for the error of his chronometers,—that is, for their deviations from *standard Greenwich time*, which is determined ultimately by the apparent motion or meridian transit of the sun at Greenwich, or by the real motion *of the earth about its axis.* The meteorologist believes that the same care and similar precautions are necessary in the case of barometers. And what he does the sailor ought to do if he wishes to derive the fullest advantage from the use of his barometer.

He must be prepared to recognize that care should be taken in the selection of a barometer in order to obtain a good and trustworthy instrument. He should have at least one mercurial barometer on board. Many sailors prefer aneroids. They are undoubtedly very handy, and generally follow and indicate changes of pressure more quickly than the marine barometers in ordinary use do. But they have one very serious disadvantage which should never be overlooked. The visible and considerable motion of the needle of an aneroid barometer is obtained by magnifying an exceedingly small motion of the lid of a closed box by means of multiplying gear or chain levers. The aneroid barometer itself is a small hollow box formed of thin steel, the elastic top of which is pressed inwards or outwards as the pressure of the air outside increases or decreases. The space through which the top of the box moves is exceedingly small. It is this motion, magnified or multiplied by suitable arrangements, which gives motion to the pointer. It is evident that a very slight change in the metal of the box or of the connecting chain-work due to climatic influences or to rough usage (as, for example, the transition from the cold of an English winter to the heat of Bombay or Calcutta in March or April) may, when exaggerated by the multiplying gear, produce a considerable change or error in the indication of the pointer. A chronometer in which the time was determined solely by means of the magnification of the motion of the hour hand,—as, for example, by microscopes,—would hardly commend itself to any one, and least of all to a sailor.

It will suffice to give a single illustration from recent experience of the very large errors of aneroids actually in use on board some steamers in the Indian seas. It may be remembered that one of the more remarkable cyclonic storms of the transition period of 1888—(*viz.*, that which formed in the Bay of Bengal in the last week of October 1888)—crossed the Peninsula, passed out into the Arabian Sea on the 2nd November as a general disturbance, acquired increased energy, and re-formed as a cyclonic storm which moved to north-east, and crossed the coast of Kathiawar on the morning of the 9th, and broke up on the 10th in West Rajputana. The chief disaster attending the storm was the disappearance of the coasting steamer *Vaitarna* with several hundreds of native passengers on board. She was apparently overwhelmed by a heavy sea, and went down with all on board. In connection with the enquiry on the loss of

that vessel, the Port Officer of Bombay asked the Meteorological Reporter for Western India to compare the aneroids in use on board of the other steamers of the line to which the *Vaitarna* belonged. He found that each vessel was, with one exception, supplied with one aneroid barometer, and that the errors of these instruments, as compared with the standard barometer at Bombay were as follows :—

Vessel.	Error of aneroid on board the steamer as determined by comparison with Bombay standard.
Steamer No. 1	·25″ too high.
„ No. 2	·37″ too high.
„ No. 3	·40″ too high.
„ No. 4	·06″ too low.
„ No. 5	No. 1 Aneroid ·56″ too high.
	No. 2 „ ·14″ too high.
„ No. 6	·03″ too low.
„ No. 7	·46″ too low.

This table shows that the errors of several of these instruments were nearly half an inch in amount,—in one case nearly half an inch too low, and in three other cases nearly half an inch too high. It is hence quite certain from what is known of the height of the barometer in ordinary storms in the Bay of Bengal and Arabian Sea, that these aneroids would give utterly unreliable and fallacious information. Thus, those aneroids which read half an inch too high would apparently indicate fine-weather conditions in the midst of a cyclonic storm, and those which read half an inch too low would give readings in fine weather such as are usually recorded with trustworthy barometers in cyclonic storms, and would apparently indicate a cyclonic storm when the weather was fine and settled. It is of course possible that the only use made of them was to ascertain when the barometer was falling or the air pressure decreasing rapidly. If this be the case, even then such instruments are of little service in showing the approach of a cyclone, as barometers rarely fall rapidly until the inner, or dangerous, portion of a cyclonic storm is close at hand.

The examination made in the India Meteorological Office at Simla of the copies of the meteorological logs of vessels, which are taken on board vessels in the ports of Calcutta and Bombay by the clerks of the India and Bombay meteorological offices, shows that the readings of the barometer actually

given cannot in many cases be accepted as correct. The clerks who take these copies make a comparison of the ships' barometers with a Calcutta standard barometer and determine the corrections of the instruments. These corrections are duly applied, and the corrected barometer readings for each day are entered in charts and compared with each other, and with the observations at the coast stations. It is found by this comparison that only about one out of three readings can be accepted as probably accurate. To the remaining readings (two out of every three received), it is necessary to apply further corrections to cover errors of observation due to various causes which can only be surmised. The following gives corrections that have had to be applied during the past four years to barometric readings taken on board three British Indian Steam Navigation Company's steamers and an Asiatic Company's steamer, all well known and well-found vessels, where these observations are probably better taken on the whole than on the majority of steamers:—

B. I. S. N. Co.'s steamship.	+·01	+·03	+·04	+·05	+·07	+·08	+·09	+·10	+·12	+·15	+·16	+·20	+·25
	−·01	−·05	−·06	−·14	−·16	−·24							
Ditto . .	+·01	+·02	+·03	+·04	+·05	+·06	+·07	+·10	+·11	+·15	+·18	+·20	+·23
	+·26	−·02	−·06	−·10	−·18	−·20	−·23						
Ditto . .	+·04	+·05	+·07	+·10	+·13	+·24	+·25	+·30	−·01	−·02	−·03	−·04	−·05
	−·06	−·10	−·16										
Asiatic Co.'s steamship.	+·02	+·03	+·04	+·06	+·07	+·08	+·10	+·12	+·13	+·14	+·17	+·20	−·02
	−·04	−·05	−·10										

It will be seen that even in the case of the best-found steamers of the largest steamship companies navigating the Bay, the barometer is occasionally read as much as two or three-tenths of an inch higher, and also occasionally as much as two-tenths of an inch lower than it really is, giving a margin of error of nearly six-tenths of an inch in the case of these vessels alone.

This statement will perhaps indicate the difficulty that meteorologists have in utilizing the barometric and other observations recorded on board ships to draw up general rules or inferences. It is self evident that accurate trustworthy rules can only be drawn up from accurate data and not from data, the margin of error of which, is so large as the preceding data indicate.

The defects of the aneroid are so well known to meteorologists that, in spite of its compact form and its sensibility, it is never used in regular observatories, or in any case where accuracy is essential, unless it can be carefully and frequently compared with a good mercurial barometer. It may hence be laid down that *aneroids should only be used so long as they can be frequently compared with a mercurial barometer to ascertain that they are in good working order and give correct indications or readings. It is only under such conditions that*

their readings can be accepted as trustworthy. It is hence necessary that all ships should have one or more mercurial barometers (by a good maker) which have been carefully compared with a standard and their errors determined, and that any aneroid on board should be employed only so long as its readings correspond with those of the mercurial barometer.

As the mercurial barometer is by far the most important meteorological instrument for use on board ship, it appears to be desirable to give a description of that particular form of it—" the marine barometer"—which is best adapted for use at sea, and of the proper methods of reading it.

The Marine Barometer.—The barometer consists essentially of a vessel of mercury, called the cistern, into which dips a glass tube, usually about 33 inches long, closed at the upper end and open below, and of a scale for measuring the height at which the upper surface of the column of mercury inside the tube stands above the level of the mercury in the cistern.

The principle upon which the use of the barometer is based is illustrated by the following experiment, first performed by Torricelli, an Italian mathematician who lived upwards of two hundred years ago.

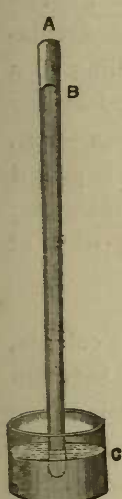


FIG. 10.

Take a glass tube (Fig. 10), about 33 inches in length, open at one end and closed at the other. Fill it with mercury, and after closing the open end with the finger, invert it, and dip the open end into a vessel containing mercury and then withdraw the finger. The upper surface of the column of mercury will fall down a little distance to the position B, where it will remain steady. If the experiment be performed near the level of the sea in fine weather the upper surface of the mercury in the tube will be found to be at a height of about 30 inches above the level of the mercury in the cistern or vessel. The upper space AB is practically a vacuum. The column of mercury in the tube is kept up, or supported, by the pressure of the air on the surface of the mercury in the cistern. This is at once proved by the fact that if the whole arrangement were put inside a large glass receiver connected with an air-pump, and the air gradually withdrawn, it would be found that the column would diminish in height at exactly the same rate as the air was withdrawn. And if the whole of the air was withdrawn, so that there was none left to press on the surface of the mercury in the vessel, the upper surface of the mercury in the tube would stand at the same level as the mercury in the vessel.

Such an arrangement as is shown in the figure, with the addition of a scale in fact constitutes a barometer in its very simplest form. Other parts are usually added, partly for the protection of the instrument (as the use of a brass tube enclosing the glass tube) and partly to enable the height of the mercury column to be measured very accurately (*e.g.*, a vernier and adjusting screws, &c.). As barometers intended for use at sea are very liable to breakage by the rolling and

pitching of the vessels, it is necessary to modify these instruments in such a way as to prevent this so far as possible. This is generally done by narrowing the tube through a considerable portion of its length. This usually prevents the rapid motion (or pumping) of the mercury in the tube, which is the chief cause of the breakage of the tubes of barometers at sea. A barometer in which such a tube is used forms what is termed a "marine barometer." The best form of marine barometer is that which is adopted by the Admiralty and the English Meteorological Office, and was approved by the Brussels Conference of Meteorologists some years ago, as the barometer best suited for withstanding the shocks due to the motion of ships and for giving accurate barometric observations. Its form and mode of suspension are shown in Fig. 11.

The cistern is made of bronzed polished iron. The frame is brass bronzed and revolves in gimbals, having a stout spring arm for suspension. The scale reads to two thousandths of an inch. The tube is contracted sufficiently to prevent oscillation of the mercury in the heaviest rolling of a ship. This kind of barometer is supplied by any of the best scientific instrument makers,—*e.g.*, Casella, Negretti and Zambra, &c.,—and is priced at £4 5*s.* in Casella's catalogue. Every sea-going vessel ought undoubtedly to be provided with at least one such barometer.

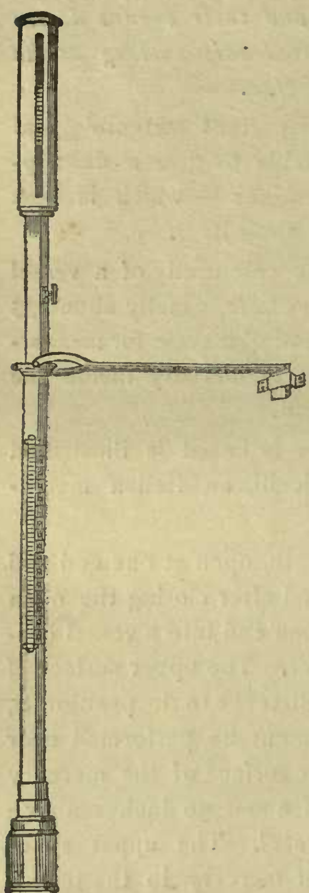


FIG. 11.

Verticality of the Barometer.—It is evident that the height of the column, which is the object of the measurement, is the distance in a vertical line between the surface of the mercury in the cistern and the top of the column. It is hence absolutely essential, for accurate measurement, that the barometer should be perfectly vertical. This is, of course, secured in the case of the marine barometer recommended for use by the mode of suspension.

Adjustment for varying level of the mercury in the cistern.—It has been stated that the height or distance to be measured by the scale attached to the barometer is that between the surface of the mercury in the cistern and the top of the mercury column in the tube. As the amount of mercury in the barometer tube and cistern does not alter, it is evident that when the top of the column sinks in the tube (*i.e.*, the barometer, in ordinary language, falls), the amount of mercury in the tube will be less, and some mercury will have passed out into the cistern and raised the level of the surface of the mercury in the cistern. The scale is,

however, fixed to the tube in marine barometers, and hence the lower end of the scale from which the measurements are made is not able to adapt itself to the surface of the mercury in the cistern, which moves slowly up and down, with the movements of the mercury column in the tube. Various contrivances have hence been devised to enable the exact height of the barometric column to be measured by the use of a fixed scale. In the case of the marine barometer, allowance is made for the rise and fall of the mercury in the cistern on the scale itself. The makers do not divide the scale into exact inches, but in such a way that the numbers as read indicate in all cases, however much the mercurial column varies, the exact height in inches from the surface of the mercury in the cistern to the top of the column. Hence, the marine barometer as thus arranged gives the exact reading without any trouble, and no subsequent correction is necessary for the changes of level of the surface in the cistern. It is in this, as in several other respects, the easiest and most convenient barometer for ordinary use.

It should be carefully noted what is meant by the top of the column. This is not a plane or flat, but a curved surface. The line which bounds the contact of the mercury with the glass is lower than the real surface would be if the tube were several inches in diameter instead of being only a fraction of an inch. If the tube were very large the surface would be almost flat and coincide in height almost exactly with the height of the top of the curved surface in a narrow tube. Hence the top, or highest point, of the curved surface should be taken as the top of the column, and not the line which bounds the contact of the mercury with the glass. The latter is unfortunately too often taken as the top by persons unacquainted with the proper method of using the barometer, and their readings are hence necessarily wrong by a certain amount depending on the inner diameter of the tube, and which consequently differs for different instruments. It should hence be most carefully remembered that *the measurement should always be taken to the highest point of the curve.* This is usually done by means of the vernier with which every good marine barometer, such as that recommended above, is provided. The vernier and the method of using it are described below.

Use of the Vernier.—The use of the vernier is to facilitate the accurate measurement of the height of the column. Each inch on the fixed scale of a barometer is generally divided into tenths and half-tenths of an inch, written 0·1 and 0·05. If, now, a length equal to 24 or 26 of these latter subdivisions be set off on an independent movable scale and divided into 25 parts; each of these latter subdivisions differs from a scale subdivision by $\frac{1}{25}$th of the latter; being in the one case less, in the other greater. Such a scale is called a vernier. Now, let the vernier and fixed scales be applied to each other, edge to edge, as in Figs. 12 and 13. If the first mark of the vernier coincide with a mark of the fixed scale, the last will coincide also, but no

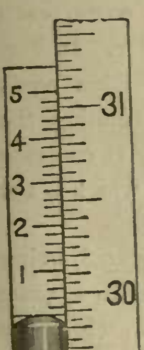


FIG. 12.

other ; and in all other cases only one mark of the vernier will coincide with a scale mark. Since each vernier division is $\frac{1}{25}$th greater or less than a scale division, the number of vernier division between the coinciding mark and the zero of the vernier will show how much this zero deviates from the scale mark next below it. If the vernier scale is equal to 24 subdivisions of the fixed scale, as is the case in the marine barometer recommended for use at sea, *it reads upwards in the same direction as the fixed scale* (Fig. 12) ; if to 26 divisions, it reads *downwards* from its own zero (Fig. 13).

FIG. 13.

The vernier scale is usually engraved on a piece of metallic tube which may be moved up and down, either directly by hand, or by means of a pinion and rack. In taking a reading, the lower edge of this tube must be made to coincide accurately with the top of the mercurial column as shown in the annexed woodcut, and this requires that *the top of the column shall be exactly on the same level as the eye of the observer* (see Fig. 14). In this position, on looking through the tube, the lower edges of the vernier slide in front and behind will coincide. To set the vernier then, raise it a little above the top of the column, get both edges in a line with the eye, and then lower it slowly till these edges form a tangent to the topmost outline or highest point of the column, no part of it being covered. If the zero line of the vernier is the lower edge of the slide and coincides exactly with one of the fixed-scale divisions, that division gives the reading. If not, take as the scale reading the division next below the edge of the vernier, and add thereto the reading of the vernier.

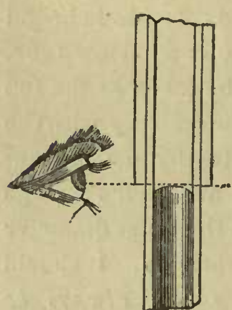


FIG. 14.

The vernier bears five principal divisions, the value of each being one-fifth of the smallest *scale* division, which in the case of the marine barometer figured on page 34 is 0·01 ; and each of these has five sub-divisions, or parts, each equal to 0·002″. The annexed figures illustrate the use of the vernier. In Fig. 12 the lower edge of the vernier intersects the scale above the division 29·85 and below 29.9. Write down 29·85 as the scale reading. Then, running the eye up the vernier, the third of the major divisions is seen exactly to coincide with a scale division. Its value, 0·03, added to 29·85, gives 29·880, which is the exact reading.

In Fig. 13, the lower edge of the vernier gives the scale reading 29·8, being above 29·8 and below 29·85. The vernier mark, which coincides with a scale mark, is the fourth beyond the vernier division marked 2, and has therefore the value 0·028. Adding this to 29·8, the exact reading 29·828 is obtained. Finally

if neither of the vernier marks exactly coincides with a scale mark, but one is a little above and the other a little below a scale division, ·001 is to be added to the reading of the lower of the two.

As a final caution, it may be mentioned that if the barometer be so suspended that the top of the column is above the eye of the observer, or if the eye is above this level, so that the front and back edges of the vernier cannot be made to coincide, the reading will invariably be *too high*. This is owing to parallax, and is illustrated by the accompanying figure (Fig. 15). The vernier *appears* to be set when its lower edge forms an apparent tangent to the meniscus of the mercury surface. If the eye be too low, the hinder edge of the vernier slide will appear to do this before the vernier is lowered to the same level; if the eye is above the top of the column, the front edge will do so. But the front and back edges of the vernier will coincide with each other, and with the mercury surface, only when all three are on the same level. Before taking the reading, the setting of the vernier must, therefore, always be verified by moving the eye up and down to ascertain, 1st, that in no position of the eye is light seen between the highest part of the surface and the edge of the vernier and 2nd, that there is one position in which the vernier conceals no part of the mercury meniscus, but only touches it.

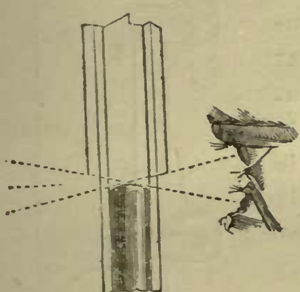


FIG. 15.

Method of reading.—First observe and write down the temperature of the thermometer attached to the barometer. If the barometer be one with a narrow tube (such as a marine barometer usually has) which acts slowly, the tube (or scale) should be gently tapped with the finger-tip before setting the vernier, and again after the first reading, when the vernier should be re-set. This should be repeated till further tapping produces no change in the reading. The barometer should be read at least twice, and when the same number has been obtained on two consecutive readings, that number should be taken as the exact reading, and entered in the log book or observation book.

Position of a Barometer.—A barometer, unlike a thermometer, *must be exposed as little as possible to changes of temperature.* The justness of the temperature correction (the necessity of which is explained in pages 40-41), depends upon all parts of the instrument having the same temperature as that shown by its attached thermometer. But the mercurial column is enclosed in a glass tube, a bad conductor of heat, and this again usually in a metal tube with an air space between. Consequently, the mercury is slow in acquiring or parting with heat, and it is only by keeping the temperature around as uniform as possible that the required conditions are even approximately fulfilled. *A baro-*

meter should therefore be kept in a well enclosed room, and the sun must never shine on it, nor must it be near a fire-place, steam pipe, or other source of heat.

The second point to be attended to is to obtain a good light, since the accuracy with which the instrument may be read depends on the lighting.

The source of light should be either on the right or left hand (not at the back, and still less opposite the barometer), and a white surface, well illumined, should be provided behind the upper part of the tube, to facilitate the accurate adjustment of the mercury level and the vernier.

For marine and other barometers, small card-clips, the form of which is shown in Fig. 16, are now constructed at the Mathematical Instrument Manufactory in Calcutta, which can be attached to the instrument, with a clean white card (C) inserted. This is the best kind of reflector that can be employed. It is adjusted somewhat more obliquely than is shown in this figure, so as to reflect the light from the right or left of the instrument.

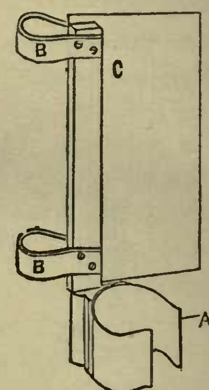


FIG. 16.

It is also desirable to note as a general rule that a barometer should never be moved from the place it has habitually occupied, unless such removal be absolutely unavoidable.

Tests of good condition of a Barometer.—When a marine barometer is in good order, if it be slowly inclined until the mercury reaches the top of the tube it gives a sharp click at the instant of contact. If the barometer fails to do this there is air in the upper part of the tube above the mercury column, and the barometer should be either repaired by a proper instrument-maker or be replaced by another. The surface of the mercury against the tube should be bright and there should be no visible air-bubbles. If the surface of the mercury be dull, it is probable that there is a thin film of air clinging to the glass. Air-bubbles, or a film of air, do not affect the readings so long as they are below the top of the column, but the air tends to move slowly upwards and to pass into the upper part of the tube above the column, and thus spoil the barometer for accurate measurement. In some barometers a special arrangement called an "air-trap" is used, by which the rise of air along the surface of the glass in the tube beyond a certain point below the top of the column is prevented, and it is desirable in purchasing a good barometer to ascertain that it is provided with such an air-trap.

Necessity for occasional comparison with a standard barometer (e.g., the Calcutta Standard Barometer).—All barometric observations in the Government observatories in India are determined or taken from barometers which ave been directly or indirectly compared wi th the Calcutta standard, and all

means, &c., given in this book are referred to that standard. As already pointed out, the necessity of such a comparison with a standard instrument is theoretically as great as is the comparison of a chronometer with a standard indicator of time,—as, for example, the dropping of a time-ball, or the firing of a gun, which is regulated by a standard clock made to keep standard mean time. The necessity of these comparisons depends upon the fact of the imperfection of human workmanship, so that it is utterly impossible to obtain two instruments which shall give exactly the same indications under the same circumstances. Fortunately, in the case of good mercurial barometers, constructed by such makers as Casella, Negretti and Zambra, Adie, Hicks, Browning, &c., it is not necessary that the comparison should be made frequently so long as the instrument is in good working order. Many of the barometers used in India have been found not to alter their errors sensibly for periods of from four to ten or twelve years. A very occasional comparison with a standard instrument would therefore be sufficient for all practical purposes, and if the captains of vessels contributing meteorological logs to the records of the India Meteorological Office expressed generally a desire to have the errors of their barometers ascertained with reference to the Calcutta standard for their own use, that office would be very willing to make arrangements to do it free of charge. The extended use of compared barometers on board ship, it is hardly necessary to say, would make the information sent in by captains of vessels to the Meteorological Office of much greater value than it is at present. The necessity of this, I may add, is strongly shown by the character of the barometric observations taken on board ships during cyclonic storms sent in to the Meteorological Office in reply to its request for such information. Many of the observations which have been contributed could not be utilized at all, in some cases because the barometers were evidently out of order, and in other cases because there were large errors in the instruments, and there were no means of ascertaining the exact amounts. I have come across cases of readings two or three-tenths of an inch too high, and also of cases as much as four or six-tenths of an inch too low. Aneroids (by good makers) which have been tested at Alipore in a vacuum chamber have been found to vary from two-tenths of an inch to three inches at different parts of their scale from the reading of a standard mercurial barometer placed in the same chamber, and mercurial barometers of cheap and common types have been similarly found to have index errors of one to five-tenths of an inch.

The great majority of sailors in using the barometer confine themselves to reading the height of the barometer and the temperature of the mercury as indicated by the attached thermometer. If the observations are to be used for accurate comparison, it is necessary to allow for change of temperature. The reason for this is explained below and the methods of allowing for it are given in the following paragraphs.

Correction of the Barometric height for Temperature.—The pressure of the air is measured by the height of a column of mercury. But the same pressure of the air may correspond to different heights of the mercurial column, which of course lengthens if it be heated. Hence simply increasing the temperature of the mercury causes it to stand or read higher. For example, suppose that a barometer was suspended in an open shed during the hot weather in Upper India, such as, in fact, is used for suspending the thermometers in order to find the temperature of the air in the open. The temperature of the air and the mercury in the barometer might probably be as much as 120°. Suppose the reading of the barometer then was 29·8 inches. If the barometer were taken into a room cooled by means of thermantidotes, and where the temperature was, say, 84°, the mercury in the barometer tube would immediately begin to fall and continue to fall until it acquired the temperature of the room (84°) and would then stand at about 29·7 inches. The pressure of the air would have remained unchanged during this time. Hence the same pressure would be measured by a barometric height of 29·8 inches when the temperature of the mercury was at 120°, and by a barometric height of 29·7 inches when its temperature was 84°, a difference of one tenth of an inch in the height of the barometric column, due solely to change of temperature of the mercury. Hence it is necessary, not merely to observe the height of the column of mercury, but also its temperature. It would, however, be very inconvenient to have to take into account at the same time the temperature, as well as the height, of the mercury in making comparisons. The meteorologist gets over this difficulty by adopting a standard temperature for the comparison of barometric readings. The actual reading (or height of the barometer) at the given temperature is by calculation reduced to the height that the mercury would stand at if its temperature were changed to that of the standard temperature. This is of course a much simpler and quicker method than that of actually warming or cooling the mercury until it acquired the fixed or standard temperature, just as it is much easier to allow for the *error* or rate of the chronometer so as to obtain from its reading Greenwich *mean time*, than it would be to be frequently moving the regulator so as to make it keep exact Greenwich mean time. The standard temperature which has been *arbitrarily* fixed upon by meteorologists is the freezing point of water (32° F.) and the process of allowing for this difference of the actual temperature from the temperature of freezing water is usually called "reducing the barometric reading to temperature 32° F." Hence every good mercurial barometer has a thermometer attached to it, which gives (if properly placed) the temperature of the mercury in the instrument (and not of the outside air). If the height of the equivalent column at the fixed temperature 32° be required, it is necessary to apply a correction to the actual reading depending on the actual temperature of the mercury, so as to give the height of an equivalent column at the fixed temperature 32°. The pressure of the air is

at the same place exactly proportional to the height of the corrected barometric column or the reduced barometric reading, and the changes of the reduced barometric readings are proportional to the pressure and the changes of the pressure of the air, and the latter can therefore be taken as a correct and reliable measure (referred to a fixed and unchanging standard) of the changes of pressure. This is what is always done in meteorological offices, and should be done by all using the barometer in Indian seas. The following table gives the corrections which should be used to reduce the reading of the barometer at any temperature, such as is likely to be experienced in the Bay of Bengal, to the fixed temperature 32° F.

When the temperature of the attached thermometer is—

between	61° and 64°	subtract	·09″	in order to obtain	the reading	reduced to 32° F.
„	65° and 68°	„	·10″	„	„	„
„	69° and 72°	„	·11″	„	„	„
„	73° and 76°	„	·12″	„	„	„
„	77° and 80°	„	·13″	„	„	„
„	81° and 84°	„	·14″	„	„	„
„	85° and 88°	„	·15″	„	„	„
„	89° and 92°	„	·16″	„	„	„
„	93° and 96°	„	·17″	„	„	„
„	97° and 100°	„	·18″	„	„	„

The preceding table explains itself. The following states the method of its use. Suppose the reading of the barometer on board a ship in the north of the Bay on a given day is 30·12″, and that of the attached thermometer is 70°. Then the table shows that for this temperature (between 69° and 72°) ·11″ is to be subtracted. Hence ·11″ taken away from 30·12″ leaves 30·01″, which is the barometric reading reduced to 32°. Similarly, if in the centre of a cyclonic storm in the Bay the actual readings of the barometer and attached thermometer were 27·65″ and 85°, the correction corresponding to 85° is ·15″, and the reduced reading would be 27·65″ less ·15″ or 27·50″. The pressure of the air at the centre would be proportional to 27·50″.

Correction to reduce the Barometer to sea-level.—This is a correction which meteorologists dealing with observations taken at land observatories are obliged to make, but which does not practically concern mariners. It is well known that the barometric height at the same place decreases if the barometer be taken up above the earth's surface. Hence it would be manifestly practically useless to compare the barometric heights at two places at different levels above the sea, without making due allowance for their difference of height above mean sea-level. It is therefore necessary to reduce the reading of the barometer in all cases where exact comparisons have to be made, to what it would be if the height of the barometer were an actual fixed amount. This is always done by referring it to the sea-level. The

allowance thus made for the elevation of the barometer at any place above the sea-level is called the reduction of the barometer to sea-level, and the modified reading of the barometer—*the barometric height reduced to sea-level.* The correction applied to reduce the barometer to sea-level is usually termed "correction to sea-level," and as increase of elevation causes the column to fall, the correction will evidently be additive. Where the height does not exceed a few hundred feet the following rule is sufficiently exact :—

To make the correction to reduce the height to sea-level, add one hundredth of an inch or ·01" for every eleven feet of elevation above the sea-level.

As, however, it is only necessary that mariners should read their mercurial barometers to one hundredth of an inch, and as barometers on board ships are not usually more than a few feet above mean sea-level, it is not necessary for them to make this correction.

Correction of the Barometric height for variable gravity (i.e., to constant or standard gravity).—This correction has only been introduced during the past few years into the reduction of observations by the India and other Meteorological Departments. The necessity for this correction will appear from the following remarks :—

The pressure of the air is measured by the height of a column of mercury. The usual statement is that the pressure measured as a force is equal to the weight of a column of mercury, the base of which measures a square foot and the height of which is equal to that of the mercury in the barometer tube. The pressure of the air is hence measured as the weight of a column of mercury. It is, however, well known that the weight of the same quantity of matter differs at different places on the earth's surface, or more exactly, in different latitudes. The weight of a body is in fact the pull of the whole earth on it and depends upon the distance of the body from the centre of the earth. The earth, it is well known, is not a true sphere in shape but a spheroid, being flattened at the poles.

The distance of the earth's surface from the centre hence decreases from the Equator to the Poles, and as the weight of a given body varies inversely as the square of its distance from the earth's centre it increases from the Equator to the Poles. This variation in the weight of bodies is of little importance except where they are of large mass or when great accuracy is required. A cargo of 5,000 tons of tea, for example, will weigh about twelve tons more at London than at Calcutta. In going from Calcutta round Ceylon on its way home, the weight will decrease three tons between Calcutta and Colombo and increase fifteen tons between Colombo and London. In other words if the weight of the tea were measured by an invariable or absolute weight-measurer, as for example a spring balance, the indications of which are constant for change of latitude and not dependent on the earth's pull or gravity, the changes of weight of the tea as thus determined would be those stated above.

As the weight of the same column of mercury hence varies from latitude to latitude, it is necessary for exactness that we should select some given latitude as the standard for the measurement of weight so that we should have a fixed and not a variable and elastic standard.

The standard latitude which has been selected is 45°, midway between the Equator and Poles.

Hence after the other corrections have been applied to the barometric readings a further correction is applied, which gives us the exact height of the barometer, supposing the air pressure were to remain absolutely unchanged and the barometer to be removed to the standard latitude 45°.

A moment's consideration will show that in lower latitudes than 45° the column of mercury for the same air pressure would be longer than at latitude 45°, in other words gravity being less a larger quantity or greater length of column would be required to give the same pressure or weight at the lower latitude. The correction for the reduction to constant or standard gravity at latitude 45° is hence negative for all latitudes less than 45°. The following gives the corrections for use in different latitudes in the Bay:—

Corrections to reduce the barometric observations to constant gravity (Lat. 45°) when the barometric reading is between 29·5 and 30·5 inches.

Lat.	
Between 0° and 10°	—·08″
Between 11° and 18°	—·07″
Between 19° and 23°	—·06″
Between 24° and 28°	—·05″
Between 29° and 30°	—·04″

The preceding paragraphs have shown that if sailors wish to make the fullest and best use of their barometric observations, they should, at the time of taking and entering the readings in their log books, make the following three corrections to every reading of the barometer:—

(1) The correction for the permanent error (or difference from the standard) of their barometer.

(2) A correction to reduce the reading at the actual temperature of the mercury to the standard temperature (32° F. or the freezing point of water).

(3) A correction to reduce the reading at the actual gravity of the place to standard gravity (Lat. 45°).

Thus, suppose that the barometer at a place in Lat. 18° reads 29·75″ and the attached thermometer 84°, and the correction for the error of the particular instrument is known to be +·06″ (that is ·06 is to be added) to the standard barometer (Calcutta for example), the following would be the calculation to find

the corrected reading to be used for purposes of comparison worked out fully :—

Actual barometric reading	29·75"
Correction for error of instrument	+·06
Reading corrected for index error	29·81"
Correction for temperature 84° (see page 41)	—·14
Reading corrected for error and for temperature	29·67"
Correction for gravity Lat. 18° (see page 43)	—·07
Reading corrected for error, temperature and gravity . . .	29·60

The corrected readings should be duly entered in the log book. It is those readings only which any person can fairly and properly use if he wishes to compare these barometric readings with those at any other place or time. If these corrections are not made, the readings are isolated and cannot be compared with others, as they have no common standard of reference. He might as well employ his own watch to time his chronometers or use an unrated chronometer to determine his longitude. When the sailor has learnt to reduce his barometric observations to a common standard and to the fixed temperature and gravity usually adopted, he is then (and not before) in a position to compare his barometric readings with others.

If an aneroid barometer be utilized to give the actual pressure for comparison with the pressure at other places, its reading (given in inches as in the case of the mercurial barometer) will require the following corrections :—

(1) For index error of the instrument (*vide* page 38).

(2) To reduce to sea-level (*vide* page 41).

(3) To reduce to constant gravity (*vide* page 42).

In other words it requires the same corrections as the reading of a mercurial barometer with one exception, *viz.*, the temperature correction. The methods of making these corrections have been fully explained in the paragraph referred to.

Aneroid barometers.—These barometers, although very compact and handy, are not used at observatories in India. They are liable to sudden changes, and are hence not sufficiently reliable or accurate enough for observational work in India*. They are, however, occasionally supplied to distant observatories to which it is hardly possible to forward mercurial barometers without certain breakage. The following paragraphs give a brief description of the aneroid barometers usually supplied in such cases :—

The aneroid barometer in the general form in which it is made consists of a brass cylindrical case about five inches in diameter and two inches deep, faced with a dial graduated and marked in the same manner as an ordinary

* Whympers' "How to use the aneroid" gives an account of the difficulties attending the use of aneroids for accurate measurements of pressure.

barometer and upon which the index or pointer shows the atmospheric pressure in inches and decimals of an inch reading to hundredths of an inch. Within the case is placed a flat metal box made of German silver, generally not more than half an inch deep and about two inches or a little more in diameter, from which nearly all the air is exhausted, The top and bottom of this box are corrugated in concentric circles, so as to yield inwardly to external pressure, and return when it is removed. The pressure of the atmosphere continually changes, and with this varying pressure, the top and bottom of the box approach to and recede from each other by small amounts; but the bottom being fixed to the base, nearly all this motion takes place at the top. The top of the box is elastic, and rises and falls according as the pressure of the air on it lessens or increases. To the eye, these expansions and contractions are not perceptible, so small is the motion. But they are rendered very evident by a delicate mechanical arrangement, communicating with a system of levers; and, by the intervention of a piece of watch-chain and a fine spring passing round the arbour, the index or pointer turns to the right or left, according as the external pressure increases or decreases. Thus, when by increase of pressure the vacuum box is compressed, the mechanism transfers the movement to the index, and it moves to the right; when the vacuum box expands under-diminished pressure, the motion is reversed, and the index moves to the left. As the index traverses the dial, it shows upon the scale the pressure in inches and decimals of an inch, exactly as is done by a mercurial barometer.

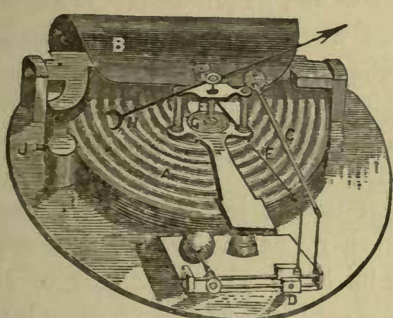


Fig 17.

The engraving (Fig. 17) represents the latest improved mechanism of an aneroid. The outer casing and face of the instrument are removed, but the index hand is left attached to the arbour. A is the corrugated vacuum box which has been exhausted of air through the tube J, and hermetically sealed by soldering, B is a powerful curved spring, resting in gudgeons fixed on the base-plate, and attached to a socket behind, F, in the top of the vacuum box. A lever, C, joined to the stout edge of the spring, is connected by the bent lever at D with the chain, E, the other end of which is coiled round, and fastened to the arbour, F. As the box, A, is compressed by the pressure of the atmosphere increasing, the spring, B, is lightened, the lever, C, depressed, and the chain, E, uncoiled from F, which is thereby turned so that the hand, H, moves to the right. In the meanwhile the spiral spring, G, coiled round F, and fixed at one extremity to the framework, and by the other to F, is compressed. When, therefore, the pressure decreases, A and B relax, by virtue of their elasticity; E slackens, G unwinds, turning F,

which carries the index hand, H, to the left. Near J is shown an iron pillar, cast as part of the stock of the spring, B. A screw works in this pillar through the bottom of the plate, by means of which the spring, B, may be so adjusted to the box, A, as to set the index, H, to read on the scale in accordance with the indications of a mercurial barometer. In the higher class of aneroid barometers, the lever, C, is formed of a compound bar of brass and steel, so arranged as to perfectly compensate for the effects of extreme variations of temperature.

Directions for using the aneroid.—Aneroids are generally suspended with the dial vertical; but if they be placed with the dial horizontal, the indications differ a few hundredths of an inch in the two positions. Therefore, if their indications are to be recorded, the instrument should be read off always in the same position.

The graduations of the aneroid scale are obtained by comparison with the correct readings of a standard mercurial barometer, under normal and reduced atmospheric pressure. Reduced pressure is obtained by placing both instruments under the receiver of an air-pump.

Aneroids are now manufactured which are almost perfectly compensated for temperature. Such an instrument, therefore, ought to show the same pressure in the external air at a temperature of, say 40°, that it would in a room where the temperature at the same time may be 60°, provided there be no difference in elevation.

The aneroid barometer, from its small size and its portability, is an admirable adjunct, and can be usefully employed where a mercurial barometer cannot be taken. It can, however, only be relied upon when frequently compared with a standard mercurial barometer. These advantages have brought it into use as a measurer of the pressure of the atmosphere to an extent that its real merits do not warrant, more especially on board ships. It requires some care, however, as its fitness for transportation is rather *apparent* than real. Slight shocks will not ordinarily disturb it, but a jar or knock that will break a mercurial barometer will, quite likely, change the reading of an aneroid by an unknown quantity, which may vary from one-tenth of an inch to one inch or even more.

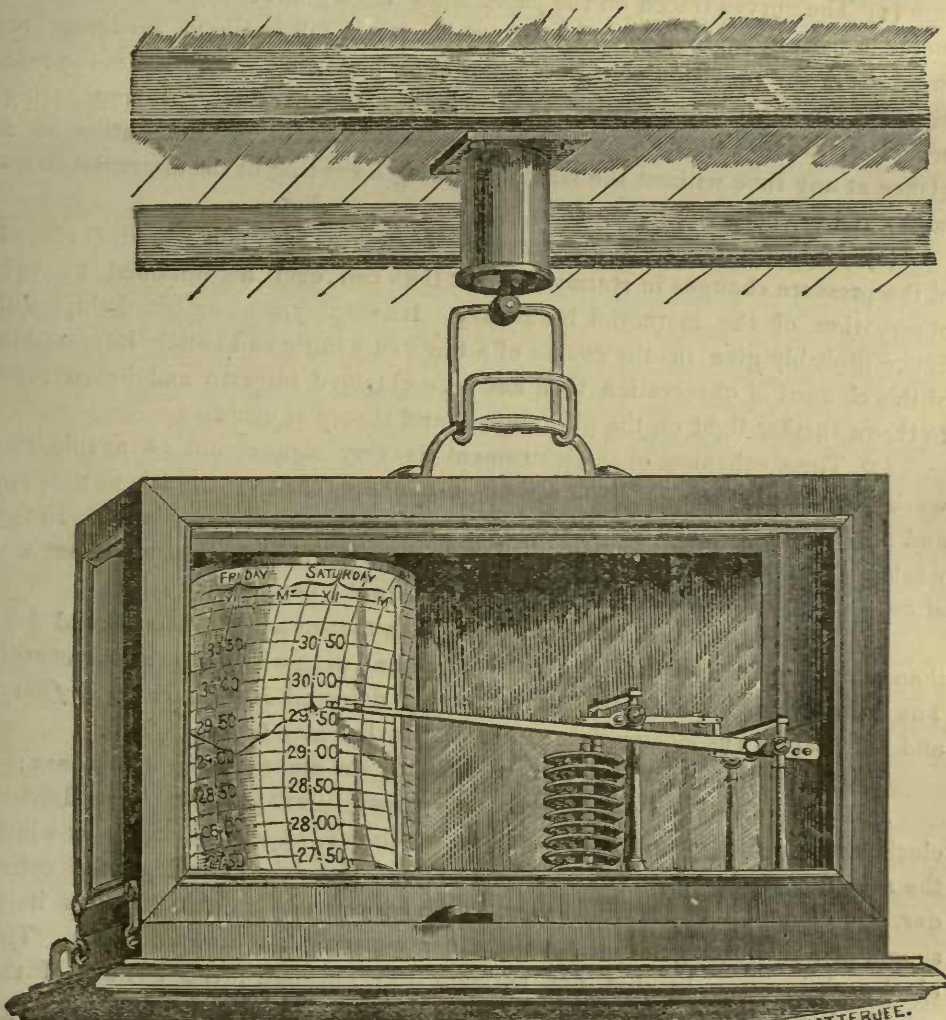
The aneroid may be hung up or placed flat on its back, but a change from one position to another ordinarily changes the readings sensibly, and therefore the instrument, while in use, should be kept constantly in one selected position and place. It is usual to adjust these barometers to the standard mercurial barometer while they are lying flat in their cases, and they should, therefore, if possible, be kept in this position. An additional merit which aneroids possess is that, being more sensitive than the mercurial, variations take place simultaneously with their causes. Like other pieces of mechanism, they are liable to derangement, which can be detected only by requent comparison with a correct standard.

Aneroid barometers, if often compared with a standard mercurial barometer, give similar indications ; but it must not be forgotten that they are not independent instruments, and that they are set originally to the reading of a mercurial barometer by means of the screw-head at the back of the case. They occasionally require adjustment, which is also effected by turning the screw-head at the back in the proper manner. They usually deteriorate in time, though slowly.

Aneroid Barograph.—A modification of the aneroid has been recently introduced which has great merits that entitle it to a place amongst the meteorological instruments used on board of all vessels.

This form of the aneroid is shown in Fig. 18 below. It differs from the

FIG. 18.



ordinary aneroid in two respects. In the first place, instead of a single vacuum chamber there are a number connected together in a vertical series, so that the total movement of the upper surface is the summation of the separate movements of each member of the series. This movement is multiplied by a series of levers as in the ordinary aneroid. The final lever is furnished with a pen at its extremity. The second important feature of this instrument is a moveable cylinder worked by a clock. On this cylinder is fastened a sheet of paper suitably ruled. The pen traces out on this moving sheet of paper a curve which shows the changes of pressure during the preceding period at a glance. In some of the instruments the cylinders revolve in a week and in others in a day. The former are the best for general use. The following are the chief advantages of the instrument :—

(1) The curves traced on the paper show at a glance whether the barometer is rising or falling and whether the rise or fall is slight, moderate or rapid. For the prevision of stormy weather an important indication is the rate oi fall of the barometer irrespective of whether the barometer is registering accurately the actual pressure. This instrument gives that information at a glance at any time without the labour of taking a reading of the mercurial barometer and of comparing it with the last pressure reading.

(2) The instrument gives a far more complete and much better record of the pressure changes in stormy weather than can ever be obtained by eye observation of the mercurial barometer. Its employment on board ships will hence probably give in the course of a few years fuller and better information of this element of observation than has been obtained hitherto and hence tend to throw further light on the phenomena and theory of cyclones.

(3) The mechanism of the instrument is very simple and, as a rule, the work of changing the paper in a good instrument, of supplying ink to the pen, and of adjusting the instrument requires less than ten minutes per week. In the weekly intervals between the change of paper it writes its story without any attention beyond the occasional supply of ink to the pen.

(4) The cost is small, not much more than that of a good aneroid and less than half the price of a carefully constructed and accurate mercurial barometer. The retail price of the aneroid barograph as depicted in Figure 18, is £5-15, and the marine suspension as represented in the same figure is £1-0.

The following are the instructions issued by the maker of the instrument :—

Recording Cylinder.—This is a very compact arrangement. The driving clock is inside the brass cylinder, around which is wrapped the paper on which the record is made. One pinion wheel projects through the end of the cylinder, and engaging with a wheel fixed to the base-plate, the clock turns itself round, and in so doing turns also the paper covering its circumference. The clockwork is carefully (but not hermetically) enclosed ; the bottom of the cylinder is closed by a sheet of brass, except that there is a hole just large

enough to let the steel axle of the above-mentioned pinion wheel go through. The top is also of brass with two sliding plates, one covering the arbor for winding, and the other covering the regulator. Proof of the efficacy of these arrangements is afforded by the fact that many of these clocks have been known to run five or more years out of doors and in dirty atmospheres without either oiling or cleaning. It is hardly fair treatment, but the result has been satisfactory. It may be pointed out that Richard's instruments being largely machine-made the parts are interchangeable, and an extra clock (applicable while the other is being cleaned) can be had for a little over £2. Clocks can be had to complete a revolution in any time desired, but those for six hours, twelve hours, twenty-four hours, and a week, are kept in stock.

Attachment of paper.—For most of the instruments special papers have been printed, both with English and metric scales. They are mostly 8 inches by 3 inches, and have merely to be wrapped round the cylinder with their ends placed under a little brass spring. In the rare event of a spring breaking, a new one can go by post for 1*s*.

The pen.—This is a very important feature in the apparatus, and must receive careful treatment. It is much the shape of the lower half of the beak of a bird, and its extremity, like that of a pen, is split. The pen must be kept clean, and this should be done, not by scraping or hard rubbing, but by washing in water with a camel's hair brush. If any particles of hair or fluff are seen near the nib, it may be cleansed by cutting off (not tearing) a small piece of writing paper and drawing it gently through the slit of the nib. The fineness or the coarseness of the trace depends chiefly upon the cleanness of the pen.

The pressure of the pen upon the paper.—In nearly every pattern the pen is slipped on to the end of a long aluminium arm, and near the other end will be seen a brass screw. As a rule, this screw should not be touched, because the instrument is adjusted before despatch; but if, owing to transit, on arrival the pen does not touch the cylinder, or presses hardly upon it, the brass screw should be so turned that the pen just lightly touches the paper, the less the better, provided the ink will flow, because if made to press hardly, friction is produced, and the full delicacy of the instrument is not obtained.

The ink.—This being largely composed of glycerine will not dry up at all readily, and works perfectly in moist climates, but in very wet and foggy ones it absorbs moisture from the air; and if the pen be very full of ink, the additional moisture may make it overflow, and the extra dilution may make the ink pale. In exceptional localities it is therefore well to fill the pen only three-quarters full, and if the trace becomes very pale to dry up the pen with a spill of blotting paper, not fluffy, and to fill with fresh ink.

Methods of barometric comparison.—The meteorologist, sitting in his office and in telegraphic communication with his observatories, makes three sets of comparisons daily, in order that he may determine when storms have

formed and are approaching any portion of the coast for which he gives storm warnings and hoists storm signals.

He first of all compares the observations taken at different stations at the same hour and day, and is thus able to ascertain the differences of the air pressure as given by the readings of the barometer (reduced for temperature and to sea-level and constant gravity) at different stations, and compares these readings and differences and the other weather conditions prevailing at that hour at the various observing stations in the area with which he deals. This kind and class of comparison is not practicable for the mariner so long as he is at sea.

The meteorologist, in the second place, compares the observations of a given day and hour with the normal or average values of the same element of observation for the period at the given place as determined by long-continued observation. This enables him to ascertain how far the weather conditions of the day differ from those proper to the day. By this comparison for all the places from which he receives his observations he is able to infer with approximate certainty the immediate consequences of the variations of the weather conditions from the normal, and to ascertain, for example, from these facts and the actual wind and other observations, the position, extent, and intensity of cyclonic storms,—and to forecast their probable future line of march and changes (either of increase or decrease, etc.) of extent or intensity with approximate accuracy. This second mode of comparison is open to the sailor to a limited extent, and it is one of great advantage in India and the Bay of Bengal, where the great majority of the weather-changes occur with a regularity and smoothness utterly unknown in temperate regions.

In the third place, the meteorologist compares the observations of the day with those taken at the same hour on the previous day, and thus learns what changes have taken place during the interval at each of the reporting stations, This third method of comparison is also open to sailors on board ships, provided they are sailing or steaming so slowly that the changes recorded by the barometer are not due to change of position, but only to the actual variations or changes in progress in that part of the Bay, or that they make allowance for change in the height of the barometer due to mere change of position. It should for such a comparison of course be carefully remembered that, at certain seasons of the year, the barometer stands at very different heights in different parts of the Bay, and hence that the mere change of position of a vessel will cause the barometer to rise or fall according as the ship is advancing in one direction or the opposite. Thus, in the height of the south-west monsoon in the Bay, the barometer on board a ship proceeding northwards from the entrance to the head of the Bay should, by mere change of position, fall from three to four-tenths of an inch in ordinary weather, and as much as five or six-tenths if a very strong monsoon be blowing.

It is hence very desirable that sailors should make, so far as is possible, similar comparisons, and thus use their barometers to the fullest advantage. The second mode of comparison is the easiest to make by sailors, and it is the one which on the whole gives the most valuable information. It is hence desirable to explain fully the simplest method of comparing the actual barometric reading on any given day and hour with the normal reading of the period at the given place. In order to make the comparison, it is necessary that the normal barometric height at the place and time of observation should be known. This is most easily done by means of charts, as will be presently explained. Unfortunately the great majority of charts published by meteorological departments, including the very valuable series giving meteorological data for the Bay of Bengal and Arabian Sea, prepared by Mr. Dallas, Assistant Meteorological Reporter to the Government of India, give the mean pressure of the day, and not the average or normal pressure at a particular hour of the day. In order to determine the mean pressure of the day, it is necessary to take a number of readings of the barometer at equal intervals—six-hourly, four-hourly, etc., and take the mean of all these,—*i.e.*, add the various observations of one day together and divide by the number of observations taken during the day. This is a slow and laborious comparison, and it is probably one which will gradually become, except in very special cases, obsolete, even in meteorological offices, for such comparisons as are here suggested. The best and simplest comparison is that between the actual barometric reading or height at a given hour and the average normal barometric height at the same place for the same hour of the same period of the year, as determined by a very large number of observations made during many years, and it is this comparison which any captain can make in two or three minutes by the use of the charts given in the present book.

Hours of observation.—It is hence necessary for the purpose of exact comparison to fix upon a certain hour or certain hours of the day for making meteorological observations and comparisons, and to take the observations at the exact local time fixed upon. This is of course always possible on land, but at sea, as the clocks are adjusted to local time at intermittent intervals, there is always a possibility of an error of several minutes in the time,—that is, 8 A.M. as indicated by the clock may not be exactly 8 A.M. local time, but may be 7-45 or 8-15 A.M.

The best hours for observation of the barometer in India and the Bay of Bengal are undoubtedly 4 A.M., 10 A.M., 4 P.M., and 10 P.M. The barometer is either at its highest or lowest at these hours, and for a little time before or after it moves so very slowly in ordinary weather as to be practically steady. An error of a few minutes, or even a quarter of an hour, in the time hence makes practically no difference in the reading of the barometer, and therefore exactness of time in making the observation is not necessary.

On the other hand, the barometer falls rapidly during the day from about 11 A.M. to 2 P.M., and an error of a few minutes in the time makes an appreciable difference in the height of the barometer. Hence, if the barometer be read at noon with the intention of comparing it with the normal barometric height at noon, considerable accuracy of time would be necessary.

Previously to April 1888 observations were taken at all observatories in India at 10 A.M. and 4 P.M., but these hours were found to be very inconvenient for the preparation of the daily weather reports, based on the daily weather telegrams, transmitted by the various observatories. It was decided to try experimentally for a few months the same hour for the morning observations as has been fixed in England and other European countries, *viz.*, 8 A.M., with a view to its final adoption as the chief hour of observation in India. It was found to work very successfully, and enables the Department to issue the various daily weather reports published at Simla, Calcutta, Madras, and Bombay much earlier in the day than was previously possible, and to hoist storm signals earlier in the day than hitherto and thus give longer notice and warning before the approach of cyclonic storms. Eight A.M. has hence been finally adopted as the chief hour (and in some cases the only hour) of observation at all the observatories in India. This change will make the meteorological observations obtained from ships of much greater value than hitherto, for 8 A.M. is one of the hours at which the barometer, the wind direction and force are recorded in the logs of ships, and it would hence be extremely desirable that ship-masters in Indian seas should make that hour the chief hour of meteorological observation, and of comparison of the actual barometric or pressure condition of the day with the normal, as shown by the charts that have been drawn up for this purpose and are given at the end of the book.

In these charts 8 A.M. has consequently been adopted as the general hour for the registration of the height of the barometer and for the ordinary comparison of the actual reading with the normal value, suggested above. The charts (Plates III to XVIII) give the normal pressure at that hour for every month in the Bay of Bengal.

Explanation of the charts giving the 8 a.m. mean pressure or height of the barometer and the mean winds for different months in the Bay.—The charts of mean pressure and wind direction given at the end of the book (Plates III to XVIII) are drawn up with the object of showing at a glance the ordinary or normal height of the barometer in the Bay of Bengal during the different months of the year. The height of the barometer as given in these charts is the height corrected for temperature, etc., as explained on pages 43-44. The charts are given for each month during the year, except for the months of May and September. During these two months pressure in the Bay changes rapidly, and hence it has been considered advisable to give two charts for each of these months, one for each half of the month, as well as the charts for the month. We strongly advise the use of the charts of the half months in these cases for com-

parison, and not the charts for the month. The latter are given in order to make the series of monthly charts complete.

On each of these charts curved lines of equal pressure, or *isobars* as they are usually termed, are drawn at unequal intervals. These curved lines, or *isobars*, play exactly the same part with respect to air pressure or barometric height that the parallels of latitude do with respect to place or position on the earth's surface. Each line runs through all places having the same ordinary or normal pressure at that period, just as a parallel of latitude runs through all places at the same distance from the equator. A number is placed near each line denoting the barometric height,—for example, 29·95″, 29·90″.

Several isobars are drawn on each chart for equal differences of pressure o ·05″, or five hundredths of an inch. Hence, in passing from a place on one line to a position on the next line to the north or south, the barometer (read at 8 A.M.) would usually rise or fall ·05″ in the month for which these lines are given.

Also, as the changes of pressure in going up or down the Bay are gradual, it is evident that the charts not only give the pressure at places or positions on the lines of equal pressure or *isobars*, but also in any intermediate position, just as the position of any place on the earth's surface (*i.e.*, its latitude and longitude) can be ascertained from the lines of latitude and longitude drawn at regular intervals on a chart when the position of the place is shown on the chart. In either case all that is required is to allow a proportional amount for the distance of the place from the next nearest line as compared with the distance of the two *isobars* between which the place or position is situated. Thus, to find the mean or ordinary 8 A.M. height of the barometer at any place not on any *isobar*, find the shortest distance between the two consecutive *isobars* within which it lies, through the given place, and also find its distance from the nearest *isobar*. Then, as the former distance (corresponding to a difference of pressure of ·05″) is to the latter, so is ·05″ to the actual difference of pressure between that at the given place and that at the nearest *isobar*. Thus, supposing in the month of May, along the meridian of 88° E., pressure falls from 29·74″ in Lat. 15° N. to 29·69″ in Lat. 19°N., and that it is required to find the pressure or barometric height in Lat. 16½° N. in the same meridian—

	Change of pressure for	4° is ·05″
∵	" "	1° " ·0125″
	and " "	½° " ·c062″

whence change for 1½° is ·0187″, or ·02″ nearly.

Hence in proceeding from Lat. 15° to Lat. 16½° N., the barometer (read at 8 A.M.) should under ordinary circumstances fall from 29·74″ to 29·74″ less ·02″ or 29·72″.

It will be evident to a sailor that the calculations can be made more quickly

and easily by the use of compasses and scale than by a rule of three question, and that the results will be accurate enough for all practical purposes.

When the reader has learnt to find from these charts the mean or ordinary 8 A.M. pressure or barometic height for any month or period, he can, by the use of the method explained on pages 56-57, find the ordinary pressure at any other hour of the day. All that is required is for him to apply in the manner there stated the number opposite to the given hour to the 8 A.M. pressure as above determined, and the sum or difference will give him the normal reading at that hour. When the sailor has learnt to find the ordinary, normal or mean 8 A.M. pressure at any season of the year at any position in the Bay, he can at once, by taking the difference between this number and the actual 8 A.M. height of his barometer (corrected for temperature, etc., as previously explained), find exactly how much the actual pressure of the air or barometer differs from the ordinary or normal pressure,—that is, the pressure which obtains during the ordinary weather of the season. This will, as we shall show in a future section, furnish him with a most valuable indication for forecasting weather, and assist him in deciding whether he is approaching a cyclonic storm.

The mariner should at least once a day (at 8 A.M.) make the comparison here suggested; and if the weather becomes threatening, he should make it at intervals of a few hours.

I would hence strongly urge sailors to have three columns instead of one or two, as is at present the usual arrangement, in their meteorological logs for the record of pressure. In the first would be given the reading of the barometer (corrected for temperature, etc., as explained in pages 43-44); in the second, the ordinary, or normal reading of the barometer for the season as determined from the charts in the manner explained above; and in the third column, the difference between these two, showing whether the actual reading is above or below the normal, and by how much. With a little practice the whole calculation would not require more than five minutes, and the mariner would be amply repaid for the labour by the additional information it would give him.

The following examples and results are given which the reader can for practice verify :—

Mean 8 A.M. pressure	in position	Latitude 10° N.,	Longitude 84° E.	in month of June .	29·75″
Ditto	do.	do.	do.	in month of July .	29·74″
Ditto	do.	do.	do.	in month of August	29·78″
Ditto	do.	do.	do.	in first fortnight of September .	29·80″
Ditto	do.	do.	do.	in second do. .	29·82″
Ditto	do.	do.	do.	in month of October	29·85″
Ditto	do.	do.	do.	in month of November . . .	29·89″
Mean 8 A.M. pressure	in position	Latitude 16° N.	Longitude 88° E.	in month of June .	29·65″
Ditto	do.	do.	do.	in month of July .	29·65″

Mean 8 A.M. pressure in position	Latitude 16° N.,	Longitude 88° E.	in month of August		29·67″
Ditto	do.	do.	do.	in first fortnight of September	29·71″
Ditto	do.	do.	do.	in second do.	29·76″
Ditto	do.	do.	do.	in month of October	29·84″
Ditto	do.	do.	do.	in month of November	29·89″

Diurnal oscillation of the Barometer.—If the mariner wishes to compare his barometric reading at any other hour than 8 A.M. with the mean, or normal barometric height, he must make allowance for the changes of the height of the barometer due to what are termed the daily tides or diurnal oscillation.

The atmospheric tides, as shown by the barometer in the tropical regions, and hence in the Bay of Bengal, go on with a regularity as marked as the oceanic tides. Moreover, as they depend on the sun only, and not upon the double action of two bodies, the sun and moon (whose position with respect to each other varies from day to day), the atmospheric tides are much simpler and steadier than the oceanic tides. There are two tides, waves or oscillations daily, exactly as in the case of the ocean. The highest pressures due to these atmospheric tides, corresponding to high water, occur at about 10 A.M. and 10 P.M., and the lowest pressures at 4 P.M. and 4 A.M. They are hence separated by six-hour intervals (of solar time). There is no such phenomenon in these tides as in the oceanic tides of spring and neap tides. There are slight differences between the diurnal rise and fall of the barometer or the height of the tide from one season of the year to another. This is of course due to the fact that the sun's action on the atmosphere varies slightly with its elevation and its distance from the earth.

And here it is as well to notice that the analogy with the oceanic tides must not be carried too far. There are many who picture to themselves the air as extending to a certain height above the earth's surface and terminating at a surface as definite as that of water, and also imagine the height of this surface alters with the diurnal tides, etc., just as the surface of the sea does by the action of the tidal wave. This is almost certainly not the case. All that we know of gases show that if they are not shut in they tend to expand indefinitely. It is possible that there are air-particles scattered throughout the whole of space, although scientific opinion is divided on that point. It is certain that they are only condensed or packed closely together near the surface of the heavenly bodies, and thus form what are called the atmospheres of those planets.

The differences in the height or amplitude of the barometric oscillation or daily tide from month to month or season to season in the Bay of Bengal are so small that the following table and results may be assumed to be true for the whole year. The quantities are given in hundredths of an inch and are the

differences between the average reading of the barometer at 8 A.M. and at the various hours specified in the first column :—

Table of corrections to reduce the mean barometric pressure at 8 A.M. in any part of the Bay of Bengal to that of any other hour of the day.

Hour.	Correction to be applied to the 8 A.M. normal barometric reading to obtain the normal reading of any hour of the day.
	"
Midnight . .	—·02 or two-hundredths to be subtracted.
1 A.M. . . .	—·04 ,, four ,, ,,
2 ,, . . .	—·05 ,, five ,, ,,
3 ,, . . .	—·06 ,, six ,, ,,
4 ,, . . .	—·06 ,, six ,, ,,
5 ,, . . .	—·05 ,, five ,, ,,
6 ,, . . .	—·04 ,, four ,, ,,
7 ,, . . .	—·02 ,, two ,, ,,
8 ,, . . .	*Nil*—no correction.
9 ,, . . .	+·01 or one-hundredth to be added.
10 ,, . . .	+·01 ,, one ,, ,,
11 ,, . . .	*Nil*—no correction.
Noon . . .	—·02 or two-hundredths to be subtracted.
1 P.M. . . .	—·04 ,, four ,, ,,
2 ,, . . .	—·06 ,, six ,, ,,
3 ,, . . .	—·07 ,, seven ,, ,,
4 ,, . . .	—·08 ,, eight ,, ,,
5 ,, . . .	—·07 ,, seven ,, ,,
6 ,, . . .	—·06 ,, six ,, ,,
7 ,, . . .	—·04 ,, four ,, ,,
8 ,, . . .	—·02 ,, two ,, ,,
9 ,, . . .	—·01 ,, one ,, ,,
10 ,, . . .	—·01 ,, one ,, ,,
11 ,, . . .	*Nil*—no correction.
Midnight . .	—·02 or two-hundredths to be subtracted.

The use of this table is very simple. Suppose that the mean barometric height

for any other hour than 8 A.M. is required at any time of the year. Look out the number opposite to the hour and subtract it from, or add it to, the mean barometric height of the place for the period or month according to the instructions given in the table. Thus, if the 8 A.M. mean barometric height in Lat. 18° N. Long. 88° E., in the month of October is 29·84″, and it is wished to find the mean barometric height at, say, 3 P.M., opposite 3 P.M. in the table is —·07″ or ·07″ to be subtracted. Hence subtracting ·07″ from 29·84″ gives 29·77″, the mean barometric height at the same place at 3 P.M. And if the actual reading of the barometer at that place at 3 P.M. on any day in October, when corrected for the error of instrument and for temperature, etc., was 29·53″, the barometer would be ·24″ lower than it would ordinarily be in fine weather at that hour in the month of October, and almost certainly be due to, and indicate the existence of a cyclonic storm in some part of the Bay, the position of which could be determined more or less exactly from the wind direction and other indications.

As the diurnal tides, or oscillation of the barometer in the Bay of Bengal, are of great interest and importance to mariners, as well as to meteorologists, the following more exact data, which have been calculated from a very large number of observations taken on board ships in the Bay, are given for reference :—

Hourly values of the diurnal variation of pressure from the mean of the day.

Hour.	Lat. 0°—10°N. Long. 80°—90°E.	Lat. 10°—20°N. Long. 80°—90°E.	Lat. 0°—10°N. Long. 90°—100°E.	Lat. 10°—20°N. Long. 90°—100°E.	Annual mean for the Bay.
	″	″	″	″	″
Midnight	+ ·0102	+ ·0083	+ ·0137	+ ·0084	+ ·0102
1 A.M.	— ·0056	— ·0069	— ·0020	— ·0062	— ·0052
2 „	— ·0196	— ·0214	— ·0175	— ·0201	— ·0197
3 „	— ·0275	— ·0300	— ·0272	— ·0285	— ·0283
4 „	— ·0264	— ·0296	— ·0280	— ·0283	— ·0281
5 „	— ·0164	— ·0193	— ·0189	— ·0188	— ·0184
6 „	+ ·0004	— ·0016	— ·0022	— ·0022	— ·0014
7 „	+ ·0194	+ ·0188	+ ·0172	+ ·0172	+ ·0182
8 „	+ ·0355	+ ·0365	+ ·0338	+ ·0343	+ ·0350
9 „	+ ·0441	+ ·0465	+ ·0426	+ ·0443	+ ·0444
10 „	+ ·0427	+ ·0462	+ ·0413	+ ·0447	+ ·0437

Hour.	Lat. 0°—10°N. Long. 80°—90°E.	Lat. 10°—20°N. Long. 80°—90°E.	Lat. 0°—10°N. Long. 90°—100°E.	Lat. 10°—20°N. Long. 90°—100°E.	Annual mean for the Bay.
	"	"	"	"	"
11 A.M.	+ ·0313	+ ·0359	+ ·0303	+ ·0353	+ ·0332
Noon	+ ·0125	+ ·0182	+ ·0125	+ ·0184	+ ·0154
1 P.M.	— ·0093	— ·0026	— ·0077	— ·0018	— ·0054
2 "	— ·0289	— ·0216	— ·0255	— ·0207	— ·0242
3 "	— ·0416	— ·0349	— ·0375	— ·0341	— ·0370
4 "	— ·0447	— ·0399	— ·0412	— ·0394	— ·0413
5 "	— ·0379	— ·0361	— ·0362	— ·0358	— ·0365
6 "	— ·0231	— ·0249	— ·0240	— ·0247	— ·0242
7 "	— ·0046	— ·0093	— ·0075	— ·0092	— ·0077
8 "	+ ·0130	+ ·0065	+ ·0092	+ ·0065	+ ·0088
9 "	+ ·0249	+ ·0184	+ ·0222	+ ·0183	+ ·0210
10 "	+ ·0284	+ ·0233	+ ·0279	+ ·0229	+ ·0256
11 "	+ ·0229	+ ·0195	+ ·0247	+ ·0193	+ ·0216

These figures give the difference between the mean pressure of the day and the mean pressure of each hour of the day, and hence necessarily differ slightly from those given in page 56. They show that the actual readings of the barometer at 1 A.M., 6 A.M., 1 P.M., and 7 P.M. very nearly agree in ordinary fine weather (that is when there are no unusual barometric movements in progress due to storms) with the mean pressure of the day. In the plates I and II given at the end of the book these numbers are charted in such a way as to show at once the actual character of the barometric movement due to the diurnal oscillation of pressure. The numbers, and hence the curves, differ slightly for different parts of the Bay. The first curve gives the mean diurnal oscillation between Lat. 0° and 10° N., and Long. 80° and 90° E.; the second between Lat. 10° and 20° N., and Long. 80° and 90° E.; the third between Lat. 0° and 10° N., and Long. 90° and 100° E.; and the fourth between Lat. 10° and 20° N., and Long. 90° and 100° E. The last curve (fig. 5) gives the mean diurnal oscillation for the whole of the Bay and is practically that upon which the figures given in page 56 are based.

It may be noted that these figures and curves have been obtained from a very large number of observations taken on board ships in the Bay of Bengal during the years 1859 to 1878 and collected by the London Meteorological Office.

A glance at the last curve will enable any one to ascertain all the more important features of the diurnal oscillation in different parts of the Bay. It shows the double character of the oscillation, and that the day tide is a larger one (or causes a greater rise and fall of the barometer) than the night tide. The first four curves also indicate that the night tide is somewhat larger in the south of the Bay than in the north. It may be added that the causes of these tides are as yet but imperfectly understood, although there can be no doubt of the general fact that they are due to the action of the sun on the atmosphere and that their regularity in the tropics is the result partly of the greater intensity of the action of the sun in the tropics, and partly to the very slight changes in the length of day and night during the year in the tropics, so that the sun acts with great regularity and uniformity the whole year round on the tropical atmosphere.

General character of the larger barometric changes in the Bay of Bengal.—It has been pointed out in the preceding paragraphs in what manner the barometer should be observed in the Bay of Bengal by those who wish to use its indications to the fullest extent, and in what manner comparisons may be made with the object of ascertaining at any time whether the actual barometric observations of the air pressure are above or below those proper to the season and by how much. If the observations be taken in the manner suggested, the mariner will find that the following principles or rules, which have been derived mainly from the observations taken at the coast stations of the Bay, hold equally for the Bay itself. These principles are fully stated, explained and illustrated in the following paragraphs:—

(*A*) *Except during the existence of the larger and more severe cyclones the barometric changes in the Bay of Bengal are always small in amount and take place very steadily and gradually.* There is none of that rapid and large fluctuation of the barometer in the Bay of Bengal such as occurs in England or the North Atlantic Ocean if the weather be the slightest unsettled. A fall of a tenth of an inch in 24 hours in any part of the Bay is certainly less frequent than a fall of half an inch, and probably less frequent over the greater part of the Bay than a fall of an inch, in the same interval in England or the British Seas. The first table which follows gives the number of times in the seventeen years 1883-99* when a fall of more than a tenth of an inch in 24 hours occurred at the coast stations of Port Blair, Diamond Island, Akyab, Chittagong, Saugor Island, Gopalpur, Cocanada, Madras, Negapatam, and

* For the eight months May to December.

Trincomalee; and the second table the number of times a rise of more than a tenth of an inch occurred during the same period—

Station.	Number of times during the seventeen years 1883-99 in which the barometer fell in 24 hours between				
	One and two-tenths.	Two and three-tenths.	Three and four-tenths.	Four and five-tenths.	Over five-tenths.
Port Blair . . .	12	...	...	...	...
Diamond Island . .	23	2	1	...	..
Akyab . . .	47	1	...	...	...
Chittagong . . .	54	3	1	...	...
Saugor Island . .	70	5	1	...	...
Gopalpur . . .	40	1	...	...	...
Cocanada . . .	26	2	...	...	..
Madras . . .	12	4	...	...	...
Negapatam . . .	3	1	...	..	...
Trincomalee . .	9	...	...	...	...
Total for Stations	296	19	3	...	...

Station.	Number of times during the seventeen years 1883-99 in which the barometer rose in 24 hours between				
	One and two-tenths.	Two and three-tenths.	Three and four-tenths.	Four and five-tenths.	Over five-tenths-
Port Blair . . .	11	...	...	..	...
Diamond Island . .	37	1	1	...	...
Akyab . . .	78	3	...	...	...
Chittagong . . .	84	7	1	...	...
Saugor Island . .	105	13	3	...	...
Gopalpur . . .	81	5	...	...	...
Cocanada . . .	41	2	...	...	...
Madras . . .	13	2	...	...	...
Negapatam . . .	5	1	...	...	...
Trincomalee . .	8	...	...	...	...
Total for Stations .	463	34	5	...	...

The preceding tables show that a rise of one-tenth of an inch is somewhat more frequent than a fall of the same amount. This is only in accordance with the general principle that in cyclonic disturbances the barometer usually rises more quickly in the rear of the storm than it falls in front.

(*B*) *An equally important feature in which the changes of pressure in the Bay of Bengal differ from those usually experienced in the British Seas or temperate regions is, that there are large regular movements of the barometer which have absolutely nothing to do with stormy or disturbed weather, and which consequently must be allowed for before we can obtain the changes of pressure caused by*

approaching bad weather or by a cyclonic storm. One of these is the daily tides or diurnal motion of the mercury in the barometer which goes on with the same regularity in fine as in unsettled weather. It is a kind of pulsation or oscillation which continues amidst all the changes and variations of weather in India, and is performed with such regularity that if it were not that it is occasionally mixed up with, and obscured by, other changes, it might be used to determine the time of day approximately. As this movement goes on equally in fine as in stormy weather, it can have nothing to do with the production of the latter, and hence this regular change must be left out of account entirely in using the barometer as an indicator of stormy weather.

Again, in the months of June, July, and August, when the south-west monsoon is fully established, there is always a difference of pressure, averaging nearly four-tenths of an inch, between the south and the head of the Bay. Hence the barometer on board a steamer going up the Bay from Galle to Calcutta will usually fall during the three or four days of the passage four-tenths of an inch in consequence of the ordinary weather conditions of the period. A smaller fall than this would probably mean much finer weather than usual, and a larger fall that a very strong monsoon was blowing over the whole of the Bay, or a cyclonic storm was in progress near the head of the Bay.

It may also be noted that even after due allowance is made for the daily oscillation, it is found that the atmospheric pressure or the height of the barometer is never absolutely steady, but, like the bob of a pendulum suspended by a long wire or string, is always moving or oscillating through small distances. Thus, in the finest and most settled weather in India, the barometer rises for a short period, usually about one to three days, and then falls for a similar period and rises again, and so on. These small oscillations appear to be almost as essential a part of the ordinary atmospheric changes as the diurnal tides, and hence are almost independent of the weather. By far the larger number of disturbances, however, appear to originate during the periods of falling barometer and hence, as might be expected *a priori*, the unsettled weather, which precedes cyclonic storms, tends to occur during the falling, rather than the rising, portion of these general barometric movements or oscillations over India.

(*C*) *The barometric changes are, as a rule, much smaller in the south than in the centre and north of the Bay.* For the barometer at the entrance of the Bay in ordinary weather does not vary more than two-tenths of an inch all the year round, rising and falling between 29·75″ and 29·95″ (leaving out of account the daily barometric tides). Whereas in the extreme north of the Bay (without taking into account the large movements during cyclonic storms) the barometer falls from an average of 30·05″ in January to an average of 29·50″ in

July, or through nearly six-tenths of an inch. Hence the total annual range or movement of the barometer is very small in the south of the Bay and increases in amount northwards.

(*D*) *The barometer in the Bay of Bengal during the period, May to November and December, to which cyclonic storms are almost entirely confined, seldom falls so much as a tenth of an inch, and very rarely so much as ·15 inch in 24 hours at the same place unless a cyclonic storm is forming in the neighbourhood of, or is advancing towards, the place of observation.* This is practically proved by the experience of the past twenty years. A portion of the evidence is summarized in the tables given below. On the assumption of the truth of this principle and of principle (*C*), it is evident that a fall of a tenth of an inch in 24 hours in the centre or south of the Bay is even a more certain indication of cyclonic or stormy weather near the place of observation than in the north of the Bay.

The following three tables give data for seventeen years in the case of thirteen coast stations round the Bay of Bengal in proof of this statement:—

STATION.	1883—86.		1887—90.		1891—94.		1895—99.		TOTAL.	
	Number of times when barometer fell between ·1″ and ·15″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·1″ and ·15″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·1″ and ·15″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·1″ and ·15″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·1″ and ·15″.	Number of falls due to cyclonic storm.
Port Blair	4	2	3	3	2	1	...	...	9	6
Diamond Island	9	4	5	4	4	4	3	3	21	15
Akyab	14	9	8	7	8	8	11	10	41	34
Chittagong	15	8	5	5	13	12	14	13	47	38
Saugor Island	18	12	16	14	17	15	10	10	61	51
False Point	13	8	8	7	18	16	15	15	54	46
Gopalpur	6	4	5	4	8	7	15	13	34	28
Vizagapatam	5	4	6	6	8	7	9	8	28	25
Cocanada	2	2	5	5	7	6	9	8	23	21
Masulipatam	4	3	1	1	3	3	8	6	16	13
Madras	1	1	...	...	...	...	6	5	7	6
Negapatam	1	1	...	...	...	...	2	2	3	3
Trincomalee	4	2	2	...	3	2	...	...	9	4
TOTAL FOR ALL STATIONS. .	95	60	64	56	91	81	102	93	353	290

Station.	1883—86.		1887—90.		1891—94.		1895—99.		Total.	
	Number of times when barometer fell between ·15″ and ·20″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·15″ and ·20″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·15″ and ·20″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·15″ and ·20″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·15″ and ·20″.	Number of falls due to cyclonic storm.
Port Blair	1	...	1	1	1	1	...	...	3	2
Diamond Island	2	1	...	...	...	...	...	...	2	1
Akyab	2	2	2	2	1	1	1	1	6	6
Chittagong	1	1	3	3	1	1	1	1	6	6
Saugor Island	2	1	1	1	3	3	3	3	9	8
False Point	...	...	2	2	2	2	1	1	5	5
Gopalpur	...	...	1	1	2	2	3	3	6	6
Vizagapatam	...	...	2	2	...	...	2	2	4	4
Cocanada	1	1	1	1	...	...	1	1	3	3
Masulipatam	...	...	...	...	...	...	...	...	...	...
Madras	2	2	2	2	...	...	1	1	5	5
Negapatam	...	...	...	...	...	...	...	...	...	...
Trincomalee	...	...	...	...	...	...	...	...	...	...
Total for all Stations .	11	8	15	15	10	10	13	13	49	46

Station.	1883—86.		1887—90.		1891—94.		1895—99.		Total.	
	Number of times when barometer fell between ·20″ and ·25″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·20″ and ·25″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·20″ and ·25″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·20″ and ·25″.	Number of falls due to cyclonic storm.	Number of times when barometer fell between ·20″ and ·25″.	Number of falls due to cyclonic storm.
Port Blair	...	...	...	...	...	...	...	...	...	...
Diamond Island	...	...	1	1	...	...	...	...	1	1
Akyab	1	1	...	...	...	...	...	...	1	1
Chittagong	1	1	...	...	1	1	...	...	2	2
Saugor Island	2	2	...	...	1	1	1	1	4	4
False Point	...	...	...	...	2	2	1	1	3	3
Gopalpur	...	...	...	...	...	...	...	...	...	...
Vizagapatam	...	...	...	...	...	...	...	...	...	...
Cocanada	...	...	...	...	2	2	...	...	2	2
Masulipatam	...	...	...	...	...	...	...	...	...	...
Madras	3	3	...	...	1	1	...	...	4	4
Negapatam	...	...	1	1	...	...	1	1	2	2
Trincomalee	...	...	...	...	...	...	...	...	...	...
Total for all Stations .	7	7	2	2	7	7	3	3	19	19

The preceding tables show that in the case of the selected stations and period the barometer fell on 421 occasions (that is 353 + 49 + 19) more than a tenth of an inch, and on 355 of these occasions (or practically in five out of six) the fall occurred during the approach of a cyclonic storm.

The second of the preceding three tables shows that the barometer fell during the period of seventeen years between ·15 inch and ·20 inch at the selected

stations on forty-nine occasions, and that on at least forty-six of these it accompanied and was caused by the approach of a cyclonic storm. The third table establishes that the barometer fell more than two-tenths of an inch in 24 hours at the same stations on nineteen occasions, and that in every case it was due to an approaching cyclonic storm.

The preceding tables also show very clearly that falls of a tenth of an inch or upwards in 24 hours are of comparatively rare occurrence in the Bay. The number is greater at Saugor Island and False Point than elsewhere. This is due to their position in the north-west angle of the Bay, nearest to the area in the north of the Bay where the great majority of the smaller storms of the rains proper (from June 15th to September 15th) are generated. Even at these stations falls of one-tenth of an inch in 24 hours do not occur on the average on more than about eight to ten days in the eight months of the year from May to December. It is also almost certain that nowhere in the Bay are falls of a tenth of an inch or upwards in 24 hours more frequent than at Saugor Island, and probable that they are less frequent. Hence it may be fairly assumed as a general principle that they do not occur in any part of the Bay more than six or eight times in the year during the cyclone season. The third table shows that falls of two-tenths of an inch or upwards in 24 hours are of extremely rare occurrence, and in fact only happen when the inner storm area of a large cyclonic storm approaches or passes over the place of observation. Such falls are not likely to happen so often as once a year at single stations, and are hence of comparatively rare occurrence.

It appears probable, *a priori*, that so far as the smaller fluctuations of the barometer from day to day in ordinary weather are concerned, they will probably be smaller in amount in the Bay than on land.

These figures hence abundantly illustrate an important feature in the meteorology of the tropics, *viz.*, the smallness of the barometric changes from day to day. The steadiness of the barometer in the tropics, as compared with the temperate regions, is, it may be stated, mainly due to the slow rate at which the velocity of the rotation of the earth's surface alters in the tropics with increasing latitude.

(*E*) *The barometer in the Bay of Bengal rarely rises a tenth of an inch in 24 hours unless a cyclonic storm is either filling up near the place of observation or has been advancing away from it.* It is not so necessary to give data for this statement, as the principle is of much less importance than the preceding. The data, however, will help to establish the general principle of the smallness of the daily barometer changes in the Indian seas, and hence further confirm the data in the preceding paragraph. They also show that rapid rises of the barometer are more frequent in the Bay than rapid falls. This is, of course, only one phase of the general principle that

the barometer rises more quickly after the passage of a cyclonic storm than it falls during its approach, or that the barometer rises more quickly in the rear of a storm than it falls in front. The following tables give data which establish the truth of this principle:—

Station.	1883–86.		1887–90.		1891–94.		1895–99.		Total.	
	Number of times when barometer rose between ·1″ and ·15″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·1″ and ·15″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·1″ and ·15″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·1″ and ·15″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·1″ and ·15″.	Number of rises due to cyclonic storm.
Port Blair	1	...	4	3	2	1	4	4	11	8
Diamond Island	7	4	2	2	9	7	12	12	30	25
Akyab	14	9	15	12	16	16	22	21	67	58
Chittagong	12	8	16	15	17	17	23	23	68	63
Saugor Island	26	13	18	17	28	27	17	17	89	74
False Point	14	7	15	13	21	20	16	16	66	56
Gopalpur	11	6	18	17	21	19	21	21	71	63
Vizagapatam	13	8	10	9	17	14	17	17	57	48
Cocanada	7	3	6	5	16	14	10	10	39	32
Masulipatam	6	4	7	7	10	10	7	6	30	27
Madras	4	2	4	4	1	1	1	1	10	8
Negapatam	3	3	2	2	...	...	...	...	5	5
Trincomalee	2	1	1	1	1	...	3	2	7	4
Total for all stations	120	68	118	107	159	146	153	150	550	471

Station.	1883–86.		1887–90.		1891–94.		1895–99.		Total.	
	Number of times when barometer rose between ·15″ and ·20″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·15″ and ·20″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·15″ and 20″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·15″ and ·20″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·15″ and ·20″.	Number of rises due to cyclonic storm.
Port Blair	...	...	1	1	...	...	...	...	1	1
Diamond Island	1	1	3	2	1	1	2	2	7	6
Akyab	2	1	4	4	3	3	2	2	11	10
Chittagong	4	3	3	3	7	7	2	2	16	15
Saugor Island	1	1	4	3	3	3	8	8	16	15
False Point	3	2	3	3	9	9	6	6	21	20
Gopalpur	2	1	1	1	4	4	3	3	10	9
Vizagapatam	3	2	1	1	2	2	1	1	7	6
Cocanada	1	1	...	...	...	...	1	1	2	2
Masulipatam	1	1	1	1	1	1	...	...	3	3
Madras	...	...	1	1	1	1	1	1	3	3
Negapatam	...	...	...	...	...	...	...	...	...	...
Trincomalee	1	1	...	...	...	...	...	...	1	1
Total for all stations	19	14	22	20	31	31	26	26	98	91

STATION.	1883–86.		1887–90.		1891–94.		1895–99.		TOTAL.	
	Number of times when barometer rose between ·20″ and ·25″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·20″ and ·25″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·20″ and ·25″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·20″ and ·25″.	Number of rises due to cyclonic storm.	Number of times when barometer rose between ·20″ and ·25″.	Number of rises due to cyclonic storm.
Port Blair	...	...	...	...	...	...	...	...	...	...
Diamond Island	...	...	...	...	...	...	...	...	...	...
Akyab	1	1	1	1	...	...	...	...	2	2
Chittagong	2	1	2	2	...	...	1	1	5	4
Saugor Island	2	2	3	3	5	5	2	2	12	12
False Point	...	...	2	1	3	3	3	3	8	7
Gopalpur	...	...	2	1	2	2	...	...	4	3
Vizagapatam	...	...	1	1	...	...	...	...	1	1
Cocanada	...	...	1	1	1	1	...	...	2	2
Masulipatam	...	...	...	...	1	1	...	...	1	1
Madras	2	2	...	...	...	...	...	...	2	2
Negapatam	...	...	1	1	...	...	..	...	1	1
Trincomalee	...	...	...	...	...	...	...	...	...	...
TOTAL FOR ALL STATIONS	7	6	13	11	12	12	6	6	38	35

(*F*) The preceding principles (more especially *C* and *D*) hence establish the following important rule:—

> *If the barometer in the Bay of Bengal during the cyclonic season lasting from May to December falls more than ·15″ in the north of the Bay—or more than ·1″ in the centre or south of the Bay in 24 hours,—that is, if the difference between the reading of the barometer at the same place and at the same hour on two consecutive days differs by amounts exceeding ·1″ in the centre and south of the Bay—or ·15″ in the north of the Bay,—it may be accepted as an almost certain indication that a cyclonic storm is forming in the neighbourhood, or that a cyclonic storm of considerable or great intensity is approaching it.*

The tables afford a measure of the probability that a fall of the barometer through the amounts stated is due to a cyclonic storm. It is also almost certain that this estimate of the probability will be below its real value for the reason already suggested, *viz.*, that the pressure changes are more frequent and larger in the India land area than in the adjacent seas. For example, the data for the coast stations show that during the cyclone season a fall of a

tenth of an inch in 24 hours immediately preceded or accompanied the formation or passage of a cyclonic storm in its neighbourhood in three cases out of four. Hence the chance or odds that a fall of one-tenth of an inch is due to an approaching cyclone is three to one. Similarly, a fall of over ·15″ in 24 hours accompanied cyclonic storms in about seven cases out of eight, or the odds that such a fall, when observed in any future year in any part of the Bay of Bengal, will be due to a cyclonic storm, would be seven to one. A fall of two-tenths of an inch in 24 hours was in every case due to a cyclonic storm, and hence may be accepted as practically a certain indication.

(*G*) An equally valuable and important principle is the following:—

It is very rare for the barometer to fall in the north of the Bay of Bengal more than two-tenths of an inch (·20″) below its normal height or more than ·15″ in the centre of the Bay, and if it does so on board a ship at any place in the north or centre of the Bay, it indicates that pressure is below the normal or ordinary pressure by that amount at least, and is an almost certain indication that a cyclonic storm has formed, or is forming, in the Bay, the position of which can be ascertained from other indications.

The daily weather reports published at Simla, Calcutta, Bombay, and Madras give the variation of the barometric readings from the normal at the coast stations for each day. The principle is based upon the information thus obtained.

The following table gives data (for May to December) for the sixteen years 1884-99, and shows how often in those years this indication was fulfilled for the ports or coast stations selected, and for which data are available:—

Station.	1884—86.		1887—90.		1891—94.		1895—99.		Total.	
	Number of occasions on which barometer fell over ·2 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·2 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·2 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·2 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·2 inch below the normal.	Number of occasions on which fall was due to storm.
Port Blair . . .	1	1	...	...	1	1	...	...	2	2
Diamond Island . .	1	1	4	4	1	1	9	9	15	15
Akyab	...	...	6	6	5	5	16	16	27	27
Chittagong . . .	1	1	6	6	10	10	19	19	36	36
Saugor Island . . .	1	1	9	9	17	17	23	23	50	50
False Point . . .	4	4	14	14	21	21	18	18	57	57
Gopalpur	5	5	9	9	4	4	10	10	28	28
Vizagapatam . . .	...	...	14	14	4	4	7	7	25	25
Cocanada	...	...	2	2	1	1	6	6	9	9
Masulipatam . . .	2	2	6	6	1	1	2	2	11	11
Madras	3	3	...	...	...	...	1	1	4	4
Negapatam . . .	1	1	1	1	...	...	1	1	3	3
Total for all stations	19	19	71	71	65	65	112	112	267	267

Station.	1884–86.		1887–90.		1891–94.		1895–99.		Total.	
	Number of occasions on which barometer fell over ·25 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·25 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·25 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·25 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·25 inch below the normal.	Number of occasions on which fall was due to storm.
Port Blair . . .	1	1	1	1	...	...	...	...	2	2
Diamond Island . .	...	...	2	2	...	...	3	3	5	5
Akyab	1	1	1	1	...	...	3	3	5	5
Chittagong . . .	...	...	1	1	2	2	5	5	8	8
Saugor Island . . .	1	1	3	3	10	10	8	8	22	22
False Point . . .	2	2	3	3	12	12	11	11	28	28
Gopalpur	...	...	3	3	1	1	3	3	7	7
Vizagapatam . . .	...	...	3	3	...	...	3	3	6	6
Cocanada . .	...	...	...	...	...	...	...	...	...	...
Masulipatam . . .	...	...	...	...	1	1	1	1	2	2
Madras	...	...	...	...	...	...	1	1	1	1
Negapatam . . .	...	...	1	1	...	...	...	...	1	1
Total for all stations.	5	5	18	18	26	26	38	38	87	87

Station.	1884–86.		1887–90.		1891–94.		1895–99.		Total.	
	Number of occasions on which barometer fell over ·3 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·3 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·3 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·3 inch below the normal.	Number of occasions on which fall was due to storm.	Number of occasions on which barometer fell over ·3 inch below the normal.	Number of occasions on which fall was due to storm.
Port Blair . . .	...	...	...	...	...	...	...	...	...	...
Diamond Island . .	...	...	1	1	...	...	1	1	2	2
Akyab	...	...	1	1	...	...	1	1	2	2
Chittagong . . .	...	...	...	...	...	...	5	5	5	5
Saugor Island . . .	1	1	1	1	7	7	5	5	14	14
False Point . . .	...	...	...	...	8	8	2	2	10	10
Gopalpur	...	...	2	2	1	1	...	...	3	3
Vizagapatam . . .	...	..	2	2	...	...	...	...	2	2
Cocanada. . . .	...	...	...	...	...	...	...	...	...	...
Masulipatam . . .	...	...	...	...	1	1	1	1	2	2
Madras	1	1	...	...	...	...	1	1	2	2
Negapatam . . .	1	1	...	...	...	...	...	...	1	1
Total for all stations	3	3	7	7	17	17	16	16	43	43

The practical bearing of the preceding rules or principles, more especially in connection with the prevision of cyclonic storms, is almost self-evident. This feature of the subject is dealt with in the next chapter.

Temperature.—Temperature is that property or state of a substance in virtue of which it can take in or give out heat, and thus become hotter or colder by interchange of heat with other bodies.

In the case of air, it is almost always measured by means of the thermometer. The instrument is too well known to need description. It is moreover one of the easiest of meteorological instruments to read and observe. It is, for almost self-evident reasons, of little or no value or use in forecasting bad weather or storms in the Bay of Bengal. It is hence unnecessary to give instructions for the best manner of exposing thermometers at sea, or to state the precautions that ought to be taken to secure the most accurate observations of temperature by its employment.

There are, however, one or two points of interest in connection with the temperature of the air in the Bay of Bengal that deserve statement.

The air, as is of course generally known, is transparent to the sun's heat far more perfectly than glass is to light. In other words, the air offers little obstruction to the passage of the sun's heat through it, and permits it to reach the earth's surface only slightly diminished in amount. The heat or light which disappears in the passage of the solar rays through the atmosphere, and is taken up by the air, is said to be absorbed, and the process is called absorption. The sun's heat, or solar radiation as it is scientifically termed, in passing through the air produces hardly any effect on it, or does not increase its temperature. It should be carefully borne in mind by all who study the changes of weather and their causes, that in clear weather the sun does not heat the air around us directly to any appreciable extent.

When, however, the sun's heat meets with a body which obstructs it and does not permit it to pass on, nor throws it off by regular reflection, as in the case of a bright piece of metal, the body becomes rapidly heated at and near the surface. Hence the action of the sun during the day is to heat the earth's surface. If this be land, and especially if it be dry land, as in the interior of India in the hot-weather months of March, April, and May, its temperature increases rapidly from sunrise until shortly after mid-day. The temperature of the earth's surface at Allahabad, for example, in the month of April, increases on the average on clear days from 65° at 6 A.M. to 136° at 2 P.M., and at Jaipur from 60° at 4 A.M. to 130° at 1 P.M., and in the most sandy tracts of Rajputana, and in Sind it probably increases even more, and perhaps as much as 80° from sunrise to mid-day. This heated surface plays the same part with respect to the air that a fire does with respect to the water in a kettle placed above it. The air at and near the earth's surface becomes heated by contact with it and tends to move upwards by the process known as convection.

Hence in the hot weather in India the earth's surface over nearly the whole of the interior of the country is heated by amounts varying with the nature of the soil from 40° to 70° or perhaps even to 80° during the morning and mid-day, and cools again by the same amount during the afternoon, evening, and night hours. This heats the air near the earth's surface very rapidly during the day, but by a smaller amount. For instance, at Allahabad the air is heated

32° on the average from sunrise to mid-day in the month of April, that is practically in the same time that the surface soil is heated 71°, and at Jaipur it is heated 25° in the same time that the ground surface is heated 70°.

Hence it is that in the months of April and May, when the ground is driest, the skies generally free from cloud, and the sun almost vertical over Central and Northern India, the mean daily temperature increases very quickly from week to week, and also the actual temperature during the day rises very rapidly from sunrise up to 1 P.M. or 2 P.M., when temperatures varying from 110° to 120° are common over the greater part of the interior of India. The result of this rapid increase of temperature during the morning is that the air is 25° to 35° or even 40° hotter in Upper and Central India than it is at the same hour of the day in the open seas to the south-east and west of India.

The conditions and actions are quite different when the sun's rays fall upon a large water surface such as the Bay of Bengal. In that case it is almost entirely utilized in evaporating water from the surface, and hence produces hardly any change in the temperature of the water. Observations of the temperature of the sea water in the deeper portion of the Bay (not in the shallows near the Bengal and Orissa coasts) show that it varies less than 2° or 3° during the day. Hence also the air overlying the water surface, the heating of which depends mainly upon the temperature of the surface it rests upon, will maintain a nearly steady temperature, not only throughout the day, but from day to day.

Hence, when it is remembered that in the Bay of Bengal the winds that prevail during the whole of the year, except in the months of December and January, and sometimes February, are sea-winds, *i.e.*, winds that advance over the surface of the sea for long distances, it will be at once evident that the temperature of the air in the Bay of Bengal will be remarkably uniform during the greater part of the year, *i.e.*, March to November. There are in the Bay of Bengal no cold land-winds or polar winds which bring down masses of cold air and thus reduce the temperature largely, as often occurs, for example, in the North Atlantic during the winter months.

Hence one of the most remarkable features of the Bay of Bengal during the whole cyclone period, April to December, is the very great uniformity of temperature. It will be sufficient to give a few facts in support of the preceding statements. During the three months March to May the mean temperature of the Bay in the open varies from 84° to 86°. From June to August it varies from 81° to 83°, so that the constant cloudy weather of this period only reduces the mean temperature 3°. From September to November it varies from 80° to 83°. And as the daily range does not exceed 3°, it will be evident that during this period of nine mon ths the temperature is rarely less than 78° and hardly ever exceeds 88°, or that the total range of temperature is about 10°.

The following table gives the mean day and night temperatures that may be

experted in each month of the year in the Bay of Bengal and the Arabian Sea away from the land, and where the temperature is that of the sea proper, uninfluenced to any large extent by the land. It also gives the daily range of temperature and the mean highest day and lowest night temperatures in the hottest part of India in each month for comparison :—

	Sea area.			Land area, hottest part of India.		
	Mean Maximum.	Mean Minimum.	Mean range.	Mean Maximum.	Mean Minimum.	Mean range.
January . . .	82·2	79·4	2·8	88·9	69·5	19·4
February . . .	83·3	80·0	3·3	97·4	72·3	25·1
March . . .	84·2	80·6	3·6	103·8	72·4	31·4
April . . .	85·5	81·7	3·8	108·0	73·0	30·0
May . . .	84·1	82·3	1·8	109·7	80·8	28·9
June . . .	83·4	81·4	2·0	107·1	82·8	24·3
July . . .	82·8	80·7	2·1	107·7	84·3	23·4
August . . .	83·8	81·1	2·7	103·4	81·7	21·7
September . . .	82·4	80·2	2·2	99·3	80·7	18·6
October . . .	82·7	79·8	2·9	100·1	66·2	33·9
November . . .	81·8	79·6	2·2	86·3	62·0	24·3
December . . .	82·6	79·6	3·0	88·6	64·0	24·6

Evaporation.—If a vessel of water be exposed, the water gradually disappears, rapidly in hot dry weather, and most rapidly if exposed to the sun in such weather, and slowly, if exposed in the shade when the air is cool or damp. The name of the process by which the visible liquid water is converted into the invisible gas called aqueous vapour is *evaporation*. The converse process by which the aqueous vapour is reconverted into water is termed *condensation.* Aqueous vapour, it should be carefully remembered, is an invisible gas, and its presence in air can only be ascertained indirectly, and it is only when it begins to condense into small drops, or globules, of water that the aqueous vapour present in the air becomes visible as mist, fog or cloud.

Condensation.—There are various methods by which the conversion of the aqueous vapour from the state of gas into that of water may be effected. The process itself is called condensation. If, for example, the invisible steam in a boiler be allowed to rush out into the comparatively cool air, it condenses into excessively small globules, which become visible, and which have the same relation to a mass of water that the particles of a piece of glass which has been

ground into fine powder bear to the original glass. If the powdered glass, consisting of an immense number of unconnected particles, be looked at, it appears to be white, whilst the glass before being powdered was transparent as water. A large number of very minute particles, or globules, of water in a cloud, for similar reasons, appear white when light falls upon them. Such masses, or large collections of small globules of water, form clouds, fogs or mist.

The colour of clouds depends mainly upon whether light is falling upon them from the sun or passing through them and to what extent. If the minute globules from any cause, either by further condensation on their surfacee, or by uniting together, increase in size, they then fall down more or less quickly (depending on the size of the drops) and give rain. It has recently been shown that electricity or electric action tends to cause small globules of water to unite together rapidly and form larger ones. This is probably the chief cause of the large size of rainfall drops in thunderstorms.

Actions accompanying condensation and rainfall.—Much might be said about the actions accompanying condensation and evaporation. It will be sufficient to consider the following examples. A mass of air containing invisible aqueous vapour rising up from the warmer valley of a hill district to the cooler hill sides and summits, may, it is well known, be cooled down sufficiently to cause the aqueous vapour to be converted into the visible form of minute drops, and produce a cloud or fog at and near the summit of the hill. When the air, carrying along with it this visible cloud, advances beyond the hill top and sinks down, the small drops are re-evaporated and pass again into the invisible state. A cloud formed in this way at and near the summit of a hill may be more or less permanent in appearance for hours or even for days. It is nevertheless in a state of constant change. Similarly, in a cyclonic area where the air is drawn in from all quarters and rises from the lower warmer strata of the atmosphere to a higher and cooler level, the aqueous vapour is condensed and forms clouds. In this case, too, the clouds are more or less permanent in appearance, whilst the aqueous vapour in passing through the cloud space is condensed, and collected into larger globules which fall as the torrential rain that invariably accompanies cyclonic storms in the tropics. Hence it is that the cloud bank, indicating the existence of a near and perhaps approaching cyclone, appears for hours almost unchanged in shape and magnitude, whilst all the time it is the seat of the most rapid and violent actions and changes.

There is one point in connection with the aqueous vapour of the atmosphere that is of very great importance. Before taking it up it is desirable to refer again as clearly as possible to one or two of the more elementary conceptions of modern science respecting work and energy.

Conversion of energy.—In order that work may be done, it is not only necessary that force should be applied, but that it should act through a distance.

For example, a coolie may exert force to support a heavy box, but he does not work unless he removes the box from one place to another—that is, exerts force on the box through the distance between the first and second place. A blacksmith will do no work, if he merely keeps a hammer suspended above a mass of iron. He must lift it up, and allow it to fall, and the more rapidly he does it (with judgment) the greater the amount of work he will do in a given time, and so on for other cases. Again, force may be exerted and work may be done either directly by man, or indirectly by utilizing with suitable machinery the forces available in nature. It may be the wind used to drive a mill or to move a ship over the ocean, or running or falling water employed to drive water-wheels, turbines, etc., or the sun and moon in producing tides, etc. But in all these arrangements, whatever does work loses something in virtue of which it was able to do work, and if this something is limited in amount it can only do a limited amount of work. This *something* is called energy. Thus every pound of coal before it is burnt contains a definite amount of energy which can be set free during the process of combustion, and by means of a steam engine, can be made to do work. But when this energy has been taken out of it,—that is, the coal has been burnt and utilized to heat the water in the boiler, and convert it into steam in order to pass it through the cylinder and drive the machinery,—it is exhausted and is of no further use for the purpose of driving the engine, and is therefore usually thrown away as refuse. This change, or loss of energy, or of power of doing work, or producing change, is continually going on in nature around us, as well as in our manufacturing towns, steam-vessels, etc. For example, the sun is constantly giving out heat (exactly like the furnace of a steamer), is and therefore yielding up or losing energy. This heat or energy thus given up produces various effects and does work of various kinds. One very important effect or kind of work performed by the sun is that of evaporation. The sun heats the surface-water of the ocean and converts it into the invisible form of aqueous vapour which passes upwards unperceived through the atmosphere until it reaches a level where it is cooled down and condenses again into the water globules of a cloud, etc. But every pound of water thus evaporated represents a certain definite amount of work done upon it by the sun which is now known very approximately, and can be calculated as easily and exactly as the horse power of the engines of a steamer, or the actual work done by an engine in a definite number of strokes, or in a given time. Also work done on a body, as in the case of a hammer or a cannon ball, gives it energy, or the power of doing work, which may again be utilized in doing work. Hence the very important principle that work and energy may, and should, be measured by the same measure, in the same way as the power of being able to pay for articles usually represented by a balance at a banker's, and the actual payments received by persons for value given should be measured in the same manner, *e.g.*, pounds sterling in England, or rupees in India.

A second important principle is that work done upon any mass of matter always produces some change, and in many cases the change thus made can be undone; and when this is the case, the body, in returning to its original state, can do an amount of work less than or equal to, but never greater than, the amount spent upon it to produce the change of state. Such changes are examples of what are called conversions or transformations of energy.

Illustrations of conversion of energy.—Thus, for example, a person does a certain amount of work in winding up the spring of his watch, and the spring, in gradually unwinding itself, does an amount of work in moving the very light and delicate wheels and pointers of his watch, which is (in consequence of friction) slightly less than the work done by the man in winding it up.

Similarly, a number of labourers engaged in pile-driving may lift up slowly a heavy mass of iron (the pile hammer) some distance and then let it drop down. The workmen, whilst lifting the pile hammer, do work in changing its position, and the pile hammer in returning to its original position gives out energy to the pile, or does work upon it, which, as before, is slightly less than the work done on the iron mass by the workman whilst lifting it. Any one thinking over the matter for himself can suggest numbers of illustrations, but the two we have given are sufficient to suggest a very important principle in connection with these changes. In the case of the watch the action of the man in winding it up is comparatively vigorous and lasts only for a few seconds. This action or energy is given up by the watch continuously for a space of, say, 24 hours, and hence the intensity of action of the watch is excessively feeble. It is an example of the conversion of a very brief but vigorous action into a prolonged feeble action.

The second illustration is an example of the opposite change. The process of lifting the pile driver or hammer is slow and laborious. A moderately strong force is exerted for a considerable interval of time by a number of workmen. The pile hammer, after falling down, acts on the head of the pile for an extremely short interval, at the instant of contact, probably for not more than a fraction of a second, and hence the intensity of the action is very great.

An important principle of conversion of energy, *viz.*, that the intensity of action varies inversely with the time of action.—Both the cases used for illustration in the preceding paragraph are analogous to the principle of the lever—with which every one is familiar. In the case of that instrument, a feeble force acting through a considerable distance, may exert or give rise at the other extremity of the lever to a large force acting through a small distance, but whatever increase of force is gained by its use, the distance through which it acts is proportionately diminished, or, as it is usually expressed, what is gained in force is lost in distance. In considering the changes or actions we are now contemplating, we have to remember that there are, as in the case of the lever, two elements. These are, in the present case, intensity of action and the

duration of the action. It is almost self-evident that in the case of any transfer of energy or performance of work by machinery, whatever we can gain in one of these elements is lost in the other. These remarks will hence illustrate the principle that in any conversion of energy what is gained in intensity is lost in time, or that the duration of the action diminishes at the same rate as the intensity increases.

Hence it is that the energy of the electrical discharge of a thunderstorm is very small indeed. It can produce very violent effects depending upon mere intensity of action, but the duration of action of a flash of lightning is so excessively small that the amount of work it can do is small, and it has been shown most conclusively by distinguished men like Faraday and Tyndall, that a few pounds of coal contain more energy and can do more work than the whole of the electricity generated during a thunderstorm.

Application of the preceding principles to the processes of evaporation and condensation.—These remarks, it will be seen, have a most important bearing on our subject.

The sun in evaporating water does a certain definite amount of work on each pound of water when changing its state into aqueous vapour. When the aqueous vapour is re-converted by any method into water and returns to the earth's surface, it yields up the energy given to it by the sun, in virtue of which it can do an amount of work practically equal to that done by the sun in evaporating it.

The most important question, in connection with this re-conversion of the aqueous vapour into water is the rate at which it takes place—that is whether the action is like that of the watch or the pile hammer after it has been acted on by man. The following reasons will show that it resembles that of the pile hammer rather than that of the watch:—

It is believed, from a large number of experiments that have been made (as for example measuring the depth of water evaporated in tanks in India, etc.), that the amount of heat energy which comes from the sun and falls on every square foot of surface of the Bay of Bengal does on the average the work of evaporating a tenth of an inch of water in one day or nearly eight ounces of water. According to some the amount may be as much as one-fourth of an inch or upwards of a pound of water per square foot of surface, or about seventy-five million tons of water per square degree of surface of the Bay of Bengal. We shall assume for the purposes of the argument that the evaporating power of the sun per square foot of surface is one-quarter of an inch, and this may hence be taken as a measure of the sun's activity at and near the earth's surface.

The sun's action or energy, it may be remarked, passes through the earth's atmosphere without doing any large amount of work upon it directly. If the opposite were the case, the upper portion of the atmosphere would be hotter than

the lower, which it is well known is not the case. The sun's heat and light action is hence on clear days transmitted almost undiminished in amount through the atmosphere, and it is only when it acts upon the surface of the earth that it produces change or does work. When it falls upon a dry land surface it heats it rapidly, and the heated surface then imparts a portion of its heat to the air by the same kind of process and motion as that which takes place when water is boiled in a kettle over a fire. It is by this kind of heating mainly that the air becomes hotter during sunny days, and not by the direct action of the sun. On the other hand, when the sun's heat falls upon the surface of water, or very damp soil, its action is almost entirely confined to evaporating the surface water. Hence the effects of sun's heat at land and sea are essentially different. In the latter case, it is continuously during the day adding to the amount of aqueous vapour in the air, but produces hardly any change of temparature in the air itself. In the former case, or in the interior of a country like India, the sun's action during the day produces indirectly very considerable changes of pressure, density, and temperature, and as the air is not contained in a closed space and is free to move, these changes are accompanied by a very considerable amount of motion, in part ascensional and in part horizontal. Hence it is over the land that many of the changes take place which initiate winds and changes of winds. For example, land and sea breezes are due to the rapid heating of the land in the day time as compared with the sea, and its equally rapid cooling at night.

And it is evident that if there were no action due to the varying amount of aqueous vapour in the air or to the processes of evaporation and condensation, the chief cause of the motion of the air or of winds would have to be sought for solely in the different heating effects in different latitudes or on land and at sea. Such actions are sufficient to explain satisfactorily the trade winds, land and sea breezes, the hot dry winds of Upper India in April and May, etc. But these are all comparatively feeble winds, and not in any way comparable in force to the violent hurricane winds of cyclonic storms in the Bay of Bengal, and it is therefore evident that these strong storm winds must be due to some other action than the heating of air by contact with surfaces of land exposed to the powerful rays of a tropical sun.

There is only one known action which appears to be adequate to explain these winds. In all the larger and more violent cyclonic storms of the Bay of Bengal there is always heavy, and almost continuous concentrated rain over the inner storm area, and frequent rain squalls in the outer storm circle, whilst beyond the area of disturbance the weather is fine and clear for very considerable distances to the north, east, and west. The character of the rainfall in the storm area itself is described in the vigorous language of sailors as "torrential," "heavy blinding rain," "rain in a solid mass," "a deluge of rain," etc. Judging

from the rainfall that occurs during the passage of cyclonic storms across India, it is almost certain that near the centre rain falls at the rate of $1\frac{1}{2}$ to 2 inches or even more per hour. The amount of rain at any place not only depends upon its intensity, but upon its duration, which in cyclonic storms depends upon the magnitude of the storm and the rate of its motion. Rainfalls of from 5 to 10 inches in 24 hours at places passed over by cyclonic storms are quite common in India after they reach land. Rainfalls of from 10 to 20 inches in 24 hours are of comparatively frequent occurrence, and of from 20 to 30 inches of occasional occurrence. Hence it is quite within the mark to assume as a fair average estimate that 10 inches of rain fall over the inner storm area of a large and intense cyclone during every 24 hours of its existence as a violent storm.

Taking the estimate of the sun's power per day to be equivalent to that required for the evaporation of a depth of one-quarter of an inch of water, it is evident that over the storm area forty times as much water would be condensed and poured down as rain, as the sun is able to evaporate in the same interval, that is, in this case the work of condensation would go on forty times as rapidly as that of evaporation goes on in the Bay in fine sunny weather. Hence also, forty times as much energy would be given out by the condensed aqueous vapour to the surrounding air as could be given by the direct action of the sun. In other words, there is in such a storm an action going on, and a conversion of energy which is very much more intense and powerful than the direct action of the sun, and can therefore produce much more rapid and greater changes and motions. If the rainfall be heavier than 10 inches per 24 hours, the action will be proportionately more intense.

The energy given up during condensation appears to be communicated to the air directly and produces rapid increase of its motion. The aqueous vapour in this case may hence be compared to the coal which is necessary to heat the boiler of a steam-engine or steam-vessel. Each of them, *i. e.*, coal and aqueous vapour, contains a certain amount of energy per pound of mass. In the one case the coal gives up its energy, by the process of burning or combustion, to the water or steam in the boiler, in virtue of which it is able to move the mechanism of the vessel. In the second case the aqueous vapour gives up a portion of its energy whilst being converted into water by the process of condensation, and communicates that energy to the air which is hence put into violent motion.

There are several important features in this transfer of energy which should be remembered :—

First.—It is a direct action or effect upon the air and not an indirect one, and is hence different from the heating of the air during the day which is due indirectly to the sun heating the earth's surface. Practically the whole of it is hence utilized in producing changes in the motion of the air.

Second.—It is continuous and not intermittent like the sun's action on the earth or the surface of water and is not suspended at night.

Third.—It is, in the case of heavy cyclonic rainfall, a very much more intense action than the direct action of the sun. If we call the ordinary action of the sun a sun-power, this action might be twenty, fifty or even one hundred sun-powers.

Fourth.—It is given out to a very limited mass of air compared with that acted upon directly by the sun. The sun's action, for example, extends almost equally over the whole of India and the Bay, and its power differs comparatively little at different places during the hot weather and rains. The action of rainfall on the contrary is local and hence produces a very large effect on a limited mass of air (or a very large local disturbance which is the primary feature of cyclonic storms), and very little at a distance of 200 or 300 miles. It hence gives rise to very great differences of condition at moderate distances, and this, it is hardly necessary to point out, is the most essential feature of a large local disturbance.

In order to ascertain the chief motive power of cyclonic storms or the energy given out during the process of condensation of aqueous vapour and of rainfall, it would be necessary for a complete enquiry to ascertain the conditions under which this action of rainfall takes place, and more especially the conditions necessary for the peculiarly concentrated and localized heavy rainfall that accompanies and maintains cyclonic storms. This, however, is not necessary in the present little work, as the chief object of these remarks has been to direct the attention of the sailor to the real motive power, and hence by inference to suggest that electricity, or temperature differences are utterly inefficient, and not to give a full account of the various theories that have been suggested at different times to explain the origin and phenomena of cyclones.

In the preceding paragraphs a very brief explanation has been given of what may be termed the motive power of cyclones. It is not, of course, a complete explanation of all the actions accompanying cyclones. To return to our illustration: it is not merely sufficient to have coal in order to produce rapid motion of a ship, but it is absolutely necessary to have a complicated apparatus and men to guide and control that apparatus or machinery. The machine or steam-engine is as necessary for the conversion of the energy of the coal into the motion of the ship as the coal itself. Similarly, in the case of cyclones, whilst the motive power is derived from the condensation of aqueous vapour, various conditions have to be fulfilled in order that this motive power may originate and maintain a cyclonic storm.

Humidity.—The process of condensation and of rainfall is of much importance in meteorology from another point of view. Aqueous vapour passes into the air by evaporation and mixes with it. A very important property of air is

that a given space, say a cubic foot, will only contain a definite quantity of aqueous vapour and no more, the quantity depending on the temperature, the higher the temperature the larger the quantity and *vice versâ*. When a given quantity of air contains the largest possible amount of vapour that it will contain at a given temperature, it is said to be *saturated*. In fact air in this respect may be compared to a sponge, which will only absorb a definite quantity of water (it may take less but not more), or a vessel of warm water which will dissolve a certain amount of salt. The air is usually not saturated, but contains a smaller amount of the invisible gas called aqueous vapour than is possible. The ratio of the actual amount it contains to the largest possible amount it could contain at that temperature is called the *humidity*, and is usually expressed as a percentage. Thus, if it contained half the largest possible amount, the humidity of that portion of air would be 50 per cent., and if three-quarters of the total possible amount without condensation, the humidity would be 75 per cent. (because 75 is ¾ths of 100). A knowledge of the humidity or amount of moisture in the air is of great importance in land meteorology. It is of very little value or interest indeed in the Bay of Bengal, because the humidity of the air near the surface of the water is always high and the air not far from saturation. The methods of obtaining the humidity are more or less complex, and as its knowledge is practically of no use to sailors in forecasting storms or ascertaining their position with respect to a storm already formed, it is unnecessary to recommend sailors in the Bay of Bengal to observe the wet and dry bulb thermometers for their own information, although of course accurate observations of the instruments taken at sea may be of great use to meteorologists for scientific investigation.

Processes of condensation of aqueous vapour in nature.—Since the air can contain less vapour in the invisible state at a lower than a higher temperature, if a given quantity of air be taken and be cooled down far enough, it will arrive at a state when it is saturated, and if it be cooled still further, it cannot contain that amount of vapour in the invisible state, and the surplus will be condensed into small globules of water, forming a visible white mass. The process of condensation in nature on the large scale is hence always due to cooling the air below the temperature of saturation by some process. There are various ways in which this may occur, but it will be sufficient to mention two. The first is by the air near the earth's surface on dry calm cold nights being cooled down by contact with the earth's surface, which cools rapidly by giving out the heat it has absorbed during the day. In this case if the cooling be sufficiently great, the air near the earth's surface will fall below the saturation point and condensation will take place, and mist or fog be formed. This method never gives rain, as it occurs through too small a depth of air for the formation of large drops and therefore for rainfall. The second, and by

far the most general cause, is due to the cooling of air that is rising higher and higher above the earth's surface. An ascending column of air is the most fruitful source of rain that occurs in nature. The reason of this is not difficult to understand. The given mass of air in rising up passes through air which presses less and less vigorously on it as it rises. In other words, the external pressure on it diminishes, The air is then able to swell out, pushing aside the surrounding air to a large extent as it rises. But in pushing aside the outside air it exerts force through a distance or does work. As a body doing work necessarily loses some power of doing work or energy, the air in expanding during its ascent loses energy, and the energy which it loses is not chemical energy, electrical energy, etc., but heat energy. It in fact acts on the same general principle that lies at the root of the action of the steam-engine. If, then, a portion of it by rising and expanding cools down, and if this motion of ascension proceed far enough, the air will cool below its saturation point and some of its invisible vapour will be converted into visible globules forming a cloud.

The measurement of humidity.—Any instrument adopted to measure the amount of moisture in the air is called a hygrometer or pychrometer, but the one best suited to use on board ship is the wet and dry-bulb hygrometer.

This hygrometer consists of two good equal thermometers, mounted on the same frame of wood, six inches wide by twelve inches long, or thereabouts, the bulb of one thermometer being naked, while the bulb of the other is wrapped in some thin absorbent covering, such as a little muslin bag, with a wick reaching from it into a small cistern of water, such as a small preserve pot or short-necked bottle.

For the instrument to act truly, great care must be taken to choose two thermometers which correspond exactly, degree for degree, from about 15° up to 100°. Both the bulbs (naked and covered, or "dry" and "wet") should project an inch or two, clear all round, below their frame, for the action of the air to be exerted on them more perfectly.

The hygrometer should be fixed in a shady place on the upper deck, about four feet from the deck, and freely exposed to the external air. The water used for the "wet" bulb should be distilled or rain-water; or, if this is not procurable, the softest pure water which can be had. *Salt-water should never be used.* The water vessel should be replenished *after*, or some little time *before*, observing, because observations are incorrect if made while the water is either colder or warmer than the air. The muslin and wick should be changed once or twice a month, according to quality and exposure to *dust* and *soot*.

The humidity can be approximately calculated from the observations of the wet and dry bulb thermometers by the following table :—

TABLE OF RELATIVE HUMIDITY.

Reading of wet-bulb thermometer.	Difference between wet and dry bulb thermometers.														
	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°
°	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
50	93	86	79	73	68	62	57	53	48	44	40	36	33	29	26
55	93	87	81	76	70	66	61	57	52	48	45	41	38	35	32
60	94	88	83	78	73	68	64	60	56	52	49	45	42	39	36
65	94	90	84	79	75	71	67	63	59	56	52	49	46	43	40
70	95	90	85	81	77	72	69	65	61	58	55	52	49	46	44
75	95	90	86	82	78	74	70	67	64	71	58	55	52	49	47
80	95	91	87	83	79	75	72	69	66	63	60	57	54	52	49
85	96	91	88	84	80	76	73	70	67	64	62	59	56	54	52
90	96	92	88	85	81	78	75	72	69	66	63	61	58	56	54
95	96	92	89	85	82	79	76	73	70	68	65	62	60	58	56
100	96	93	89	86	83	80	77	74	71	69	66	64	62	59	57

In the first vertical column is given the reading of the wet bulb thermometer and in the upper horizontal column the difference between the readings of the dry and wet bulb.

Thus suppose the wet bulb reads 75° and the difference between the dry and wet bulb is 7°, go down the first vertical column to the number 75°, then look down the vertical column headed by the number 7° until we come to the horizontal column commencing with number 75°, and the number thus obtained, 70, will be the humidity of the air as given by the observation.

For numbers not given in the first column it will be sufficient to take the nearest number in that column.

Thus for temperature of wet 84° and difference between wet and dry bulb 3° look along horizontal column beginning with number 85° (nearest to 84°) and in the vertical column headed 3° and humidity will be found to be 88.

Rainfall.—It has been already pointed out that the enormous energy of cyclones in the Bay of Bengal is almost entirely derived from the change of the aqueous vapour present in the air into rain by the process of condensation. As the largest and most intense cyclones in the Bay of Bengal are far more severe and intense than storms in the temperate regions of the Atlantic Ocean,

and have features which are either absent or are not conspicuous in those storms, as, for example, storm waves, calm centres, etc., this would naturally suggest that the rainfall in tropical cyclones is almost certainly much greater than ever occurs in the storms of the North Atlantic Ocean. This cannot be proved by actual measurement of rainfall at sea, as no satisfactory method has yet been generally introduced for measuring rain on board ships. The descriptions of cyclonic storms in tropical seas, as given in the logs of vessels, however, abound in expressions evidencing the extraordinary intensity of the rainfall. The following are quoted from logs which have been sent in during recent storms in the Bay of Bengal:—"Terrific rain," "Sheets of rain," Torrents of rain," "Blinding rain," "Continuous heavy rain," "Steady hard rain," "Thick rain," "Incessant rain," "Thick blinding rain," "Deluge of rain," "Rain coming in a solid mass," etc.

As the storms which form in the Bay of Bengal all pass landwards into India, the rainfall which occurs during their march across Northern or Central India will give an estimate of the amount of rain which falls under favourable cyclonic conditions and during cyclonic storms in the tropics. The following are some of the more remarkable rainfalls in India during the past 22 years:—

Table showing the more remarkable rainfalls in 24 hours in different parts of India, during the period 1878-99.

Year.	Month.	Date.	District.	Station.	Amount of fall in 24 hours.	Remarks.
					Inches.	
1878	June	19	Khasi and Jaintia Hills.	Jowai	20·60	
	August	26		Do.	23·40	
	„	...		Cherra Poonjee	24·60	
	„	27		Jowai	26·70	
	October	31	Kolhapur	Shirol	20·00	
1879	June	4	Khasi and Jaintia Hills.	Jowai	22·70	
	September	13	Purnea	Purnea	35·38	During a small cyclonic storm.
1880	August	11	Khasi and Jaintia Hills.	Cherra Poonjee	27·13	
	„	13		Jowai	22·96	
	September	18	Bijnor	Nagina	32·40	During a cyclonic storm.
	„	...	Do.	Dhampur	30·40	Ditto.
	„	...	Do.	Najibabad	28·50	Ditto.
1882	June	3	Ratnagiri	Dapoli	21·08	Ditto.
	„	4	Do.	Chiplun	21·00	Ditto.

Table showing the more remarkable rainfalls in 24 hours in different parts of India, during the period 1878-99—(concluded).

Year.	Month.	Date.	District.	Station.	Amount of fall in 24 hours.	Remarks.
					Inches.	
	June . .	16	...	Sutna . . .	22·15	During a cyclonic storm.
	,, . .	18	Cawnpore . .	Derapur . .	20·00	Ditto.
	July . .	7	Bareilly . .	Nawabgunj . .	21·00	Ditto.
	October . .	3	Pâtna . . .	Gopalgunj . .	22·02	Ditto.
1885	June . .	14	Khasi and Jaintia Hills.	Jowai . . .	22·30	
	,, . .	15		Do. . . .	29·20	
	July . .	2		Do. . . .	22·60	
	September .	9		Do. . . .	24·36	
	,, .	8		Cherra Poonjee .	22·11	
1886	June . .	18	Colaba . . .	Roha . . .	24·80	During a cyclonic storm.
1887	,, . .	1	Khasi and Jaintia Hills.	Cherra Poonjee .	22·90	
	,, . .	25		Do. .	25·04	
1888	May . .	27		Jowai . . .	30·20	
	June . .	26		Do. . . .	22·50	
	,, . .	27		Mahadeo . .	25·80	
1889	June . .	22	Khasi and Jaintia Hills.	Cherra Poonjee .	22·80	
	,, . .	23	Do. . .	Do. .	22·60	
1890	,, . .	5	Do. . .	Do. .	24·25	
	,, . .	13	Do. . .	Do. .	30·04	
	,, . .	25	Do. . .	Do. .	21·32	
	,, . .	29	Rangpur . .	Bhawaniganj (Gaibanda).	27·00	
1891	July . .	28	Surat . . .	Jalalpor. . .	25·85	
1892	March . .	30	Khasi and Jaintia Hills.	Cherra Poonjee (Police Station).	29·11	
1893	April . .	,,	Noakhali . .	Noakhali . .	20·67?	
	May . .	,,	Cachar . . .	Nemotha . .	27·30	
	July . .	23	Khasi and Jaintia Hills.	Cherra Poonjee (Police Station).	20·80	
	August . .	11	Do. . .	Do. . .	27·20	
	September .	16	Jodhpur . . .	Sachor . . .	20·15	
1895	July . .	9	Khasi and Jaintia Hills.	Cherra Poonjee .	20·95	
	September .	6	Godavari . .	Amalapuram . .	20·01	
1897	,, . .	4	Khasi and Jaintia Hills.	Cherra Poonjee (Mission Dispensary).	24·20	
1898	August . .	25	Do. . .	Do. . .	25·15	
1899	September .	25	Darjeeling . .	Darjeeling . .	19·40	During a cyclonic storm.

Captain Woolward of the F. L. V. *Hesperus* has had under observation a raingauge suitably suspended during the past three years. The following gives the heaviest rainfall in 24 hours recorded by him during that period :—

Year.	Month.	Date.	Amount of fall exceeding 5 inches measured in 24 hours.
			Inches.
1899	May.	15th	5·06

Cloud Observation.—The observation of clouds is very important. By means of observations of the forms of clouds and of the direction in which they are moving, it is often possible to obtain early indications of the approach of a cyclonic storm, or of bad weather, some hours before the barometer begins to fall.

Cloud observation requires much practice and intelligence, as it depends mainly upon the judgment of the observer, and not at all upon taking a measurement by means of an instrument. Sailors are usually good observers of clouds, and it is much to be wished that they would record their observations fully and send them into Meteorological Offices, more especially in India, where cloud observation is the least satisfactory part of the work of our observers.

There has been much difference of opinion amongst meteorologists until recently, as to the best methods of observing, naming, and describing clouds. A few years ago, an International Meteorological Committee was appointed to devise the most suitable method of observing clouds. The Committee prepared a cloud atlas showing by lithographic pictures prepared from actual photographs, the chief forms of clouds and suggested a division of cloud forms and a suitable nomenclature for general adoption. The division and nomenclature of clouds suggested by the International Committee were adopted by the India Meteorological Department in the year 1890 and are regularly employed by observers at all the Indian observatories as in all the large European countries.

What a cloud is.—A cloud is an aggregate of very small particles of condensed water vapour, either in the liquid form of water or the solid form of ice. Hence a cloud may be regarded as a mass of "water dust" or "of ice or snow dust." If aqueous vapour is condensed in the lower strata of the atmosphere where the temperature is above 32° or the freezing point, it takes the form of very small globules of water. If, on the other hand, it is condensed in the higher regions of the atmosphere where the temperature is below 32°, it is converted into tiny crystals of snow.

Object of cloud observation.—Cloud observations, as usually made, include estimates of the amount, form, and movement of cloud. The form and motion of clouds give us the only information we can obtain, without the use of balloons, of the changes in progress in any part of the atmosphere removed

from the earth's surface and of the direction and rate of motion of the higher strata. Barometers, thermometers, wind-vanes, etc., tell us the conditions (such as, for example, pressure and temperature and direction of motion) of the air at the place of observation only, and hence at or very near the earth's surface.

The existence of a cloud at any elevation indicates that the atmosphere in the space occupied by the cloud is in a state of saturation, and that the vapour is being condensed. The shape of the cloud also tells us some of the conditions under which this air space became saturated and the cloud was formed, and hence indicates to some extent changes which are going on in the air above us and may affect the weather at the earth's surface. Finally, their direction of movement shows what winds are blowing high up in the air. The observer is thus enabled by comparing the direction and rate of motion of the air at the earth's surface and at different heights in the atmosphere to ascertain whether weather is settled or unsettled, and what changes in the weather may be expected.

Cloud proportion.—The proportion of the sky covered by cloud is estimated by simple inspection. A sky wholly overcast is recorded as '10' and all minor degrees of cloudiness by the lower numbers from 9 downwards, the figure '0' being used to indicate an unclouded sky. From the nature of the observation an approximate estimate only is possible; but with a little practice it will be found easy to make it with sufficient accuracy for practical requirements.

Kinds of Clouds.—Clouds may be roughly divided in respect of their apparent shape and form into two great classes—first, separate or globular masses (most frequently seen in dry weather), and second, forms which are widely extended, or completely cover the sky (chiefly occurring in wet weather). Each of these two forms is subdivided, partly according to their shape and partly according to their altitude.

The following gives the classification of clouds arranged chiefly in order of their elevation as used by observers at meteorological observatories in India:—

A. Upper clouds, average altitude about 30,000 feet:—

- 1. Cirrus | 2. Cirro-stratus.

B. Intermediate clouds, between 10,000 feet and 25,000 feet in elevation:—

- 3. Cirro-cumulus.
- 4. Alto-cumulus. | 5. Alto-stratus.

C. Lower clouds, averaging 7,000 feet in elevation:—

- 6. Strato-cumulus. | 7. Nimbus.

D. Clouds of diurnal ascending currents:—

- 8. Cumulus; base 5,000 feet in elevation.
- 9. Cumulo nimbus; apex, 10,000 feet to 27,000 feet and base, 5,000 feet in elevation.

E. High Fogs, under 3,000 feet.

- 10. Stratus.

The following gives a description of these forms so far as is possible in words :—

1. *Cirrus* (*Ci.*).—Detached clouds, delicate and fibrous looking, taking the form of feathers generally of a white colour, sometimes arranged in belts which cross a portion of the sky in "great circles", and by an effect of perspective, converge towards one or two opposite points of the horizon (the Ci. S. and the Ci. Cu. often contribute to the formation of these belts).

2. *Cirro-Stratus* (*Ci. S.*).—A thin, whitish sheet, at times completely covering the sky and only giving it a whitish appearance (it is then sometimes called *cirro-nebula*), or at others presenting, more or less distinctly, a formation like a tangled web. This sheet often produces halos around the sun and moon.

3. *Cirro-Cumulus* (*Ci. Cu.*).—Small globular masses or white flakes without shadows, or having very slight shadows, arranged in groups and often in lines.

4. *Alto-Cumulus* (*A. Cu.*).—Largish globular masses, white or greyish, partially shaded, arranged in groups or lines, and often so closely packed that their edges appear confused. The detached masses are generally larger and more compact (changing to S. Cu.) at the centre of the group ; at the margin they form into finer flakes (changing to Ci. Cu.). They often spread themselves out in lines in one or two directions.

5. *Alto-Stratus* (*A. S.*).—A thick sheet of a grey or bluish color, showing a brilliant patch in the neighbourhood of the sun or moon, and which, without causing halos, may give rise to coronæ. This form goes through the same changes as Cirro-stratus, but its altitude is much less.

6. *Strato-Cumulus* (*S. Cu.*).—Large globular masses or rolls of dark cloud frequently covering the whole sky, especially in winter, and occasionally giving it a wavy appearance. The layer of strato-cumulus is not, as a rule, very thick, and patches of blue sky are often visible through the intervening spaces. All sorts of transitions between this form and Alto-cumulus are noticeable. It may be distinguished from nimbus by its globular or rolled appearance, and also because it does not bring rain.

7. *Nimbus* (*N.*) *Rain-cloud.*—A thick layer of dark clouds, without shape and with ragged edges from which rain or snow generally falls. Through the openings in these clouds an upper layer of Cirro-stratus or Alto-stratus may almost invariably be seen. If the layer of nimbus separates up into shreds or if small loose clouds are visible floating at a low level underneath a large nimbus, they may be described as *Fracto-nimbus*. ("Scud" of sailors.)

8. *Cumulus* (*Cu.*) (*Wool-pack Clouds*).—Thick clouds of which the upper surface is dome-shaped and exhibits protuberances while the base is horizontal. These clouds appear to be formed by a diurnal ascensional movement which is almost always observable. When the cloud is opposite the Sun, the surfaces usually presented to the observer have a greater brilliance than the margins

of the protuberances. When the light falls aslant, these clouds give deep shadows, and when on the contrary, they are on the same side as the sun, they appear dark, with bright edges. The true cumulus has clear, superior, and inferior limits. It is often broken up by strong winds, and the detached portions undergo continual changes. These may be distinguished by the name of *Fracto-cumulus.*

9. *Cumulo-Nimbus* (*Cu.N.*).—Frequently termed Thunder-cloud and Shower-cloud. Heavy masses of clouds, rising in the form of mountains, turrets, or anvils, generally having a sheet or screen of fibrous appearance above ("false cirrus") and underneath, a mass of cloud similar to "nimbus." From the base there usually fall local showers of rain or of snow (occasionally hail or soft hail). Sometimes the upper edges have the compact form of cumulus, forming into massive peaks round which delicate "false cirrus" floats, and sometimes the edges separate into a fringe of filaments similar to that of the cirrus cloud. This last form is particularly common in spring showers. The front of thunderclouds of wide extent frequently presents the form of a large bow spread over a portion of the sky which is uniformly brighter in colour.

10. *Stratus* (*S.*).—A horizontal sheet of lifted fog. When this sheet is broken up into irregular shreds by the wind, or by the summits of mountains, it may be distinguished by the name of *Fracto-stratus.*

The cloud forms numbered 1, 3, 4, 6, 8, and 9 consist usually of separate and globular masses and are most frequently seen in fine weather.

Forms numbered 2, 5, and 7 are, on the other hand, usually widely extended completely covering the whole or a part of the sky and are usually seen in wet weather.

Instructions for cloud observation.—The following are the instructions for the observation of the clouds issued by the International Committee for cloud observation.

For each observation the following points should be noted and entered in the register :—

1. *The kind of cloud, indicated by the international letters of the name of the cloud.*

2. *The direction from which the clouds come.*—By remaining perfectly still for several seconds, the movement of the clouds may easily be observed in relation to a steeple or pole erected in an open space. If the movement of the cloud is very slow, the head should be steadied by using a rest. This method of observing must only be used for clouds near the zenith, for if they are distant from it perspective may lead to errors. In such cases a nephoscope alone will give correct results.

3. *The point of radiation of the upper clouds.*—These clouds often take the form of narrow parallel lines, which by reason of perspective appear to issue from a given point on the horizon. The "point of radiation" is the name given to the point where these belts or their prolongations meet the horizon.

This point on the horizon should be indicated in the same manner as the direction of the wind, *e.g.*, N, NNE, etc.

4. *Undulated clouds.*—It often happens that the clouds have the appearance of regular striæ, parallel and equidistant, like waves on the surface of water. This is most frequently the case with cirro-cumulus and strato-cumulus (roll cumulus). It is important to note the direction of these striæ. When two distinct systems are apparent, as is often seen in clouds separated into globular masses by striæ in two directions, the directions of these two systems should be noted. As far as possible, these observations should be taken of striæ near the zenith, so as to avoid errors caused by perspective.

5. *The density and situation of a bank of cirrus.*—The upper clouds often assume the form of a tangled web or sheet, more or less dense which, as it appears above the horizon, looks like a thin bank of a light or greyish colour. As this form of cloud is closely connected with barometrical depressions, it is necessary to observe :

a. Its density, whether,
- (1) very thin and irregular,
- (2) thin, but regular,
- (3) fairly thick,
- (4) thick, or
- (5) very thick and of a dark colour.

b. The direction in which the sheet or bank appears thickest.

6. *Remarks.*—All interesting particulars should be noted, such as :

a. During summer all low clouds, as a rule, assume special forms, resembling more or less cumulus. In such cases an entry should be made in the column for " Remarks ", *stratus* or *nimbus cumuliformis.*

b. It sometimes happens that a cumulus presents a mammillated lower surface. This appearance should be noted under the name of *mammato-cumulus.*

c. It should always be noted whether the clouds seem to be stationary or in very rapid motion.

International symbols for cloud forms.—The following gives the International designations for the cloud forms mentioned above, as suggested by the International Committee :—

Ci. . .	Cirrus.	Cu. N. . .	Cumulo-nimbus.
Ci. S. . .	Cirro-stratus.	S. . . .	Stratus.
Ci. Cu. . .	Cirro-cumulus.	Fr. Cu. . .	Fracto-cumulus.
A. Cu. . .	Alto-cumulus.	Fr. N. . .	Fracto-nimbus.
A. S. . .	Alto-stratus.	Fr. S. . .	Fracto-stratus.
S. Cu. . .	Strato-cumulus.	S. Cf. . .	Stratus cumuliformis.
N. . .	Nimbus.	N. Cf. . .	Nimbus cumuliformis.
Cu. . .	Cumulus.	M. Cu. . .	Mammato-cumulus.

CHAPTER II.

BRIEF DESCRIPTION OF THE NORMAL WEATHER AND CURRENTS IN THE BAY OF BENGAL, MONTH BY MONTH, THROUGHOUT THE YEAR.

The present chapter gives a brief description of the weather and currents usually experienced in the Bay of Bengal during the year.

The Bay of Bengal is included within the larger area known as the Indian monsoon region in which winds from opposite directions prevail during the two divisions of the year known as the north-east monsoon (or season of north-east winds in the Indian seas) and the south-west monsoon (or season of south-west winds in the Indian seas).

The North-East monsoon.—The north-east monsoon conditions are most fully established in the months of January and February.

In these months pressure is highest in Northern India and Central Asia (including Persia), decreasing southwards to the south of the equator and thence increasing again southwards to Lat. 25° or 30° in the Indian Ocean. The general air movement in the Indian seas and India in these months is from north to south. These northerly winds in the open seas are deflected by the action of the earth's rotation (for the explanation of which, see para. 2, page 14) to the right and hence are from north-easterly directions. These north-east winds during this period are similar in their origin to the north-east trades in the Atlantic and Pacific Oceans, the chief difference being that the latter are permanent winds, whilst the former are seasonal winds only.

As pressure is always higher in the centre and south of the Indian Ocean than in and near the Equatorial belt, the air movement is always from south with a deflection from east due to the earth's rotation (which is to left in the southern hemisphere). These south-east winds are permanent and not seasonal, and are the south-east trades winds of the Indian Ocean.

The intermediate area between the south-east trades of the Indian Ocean and the north-east winds of January and February in the Indian seas is a region of light unsteady winds and calms, much rain, frequent thunderstorms, and squalls. It corresponds to the Doldrums of the Atlantic and the Pacific Oceans.

As these northerly winds over the Indian seas are the continuation of an air movement from the interior of India and the countries to the north and west, they are comparatively dry and cool. Hence during their full prevalence dry cool weather with little or no cloud obtains over the greater part of the Bay of Bengal. Conditions begin to change in the latter half of February or the

first half of March due to the increasing influence of the sun or of the solar heating action which gives rise to a steady and continuous increase of temperature over the whole Indian land and sea areas. The increase is considerably greater over the land than over the sea. Hence the air begins to draw into the land from the neighbouring seas. This is chiefly exhibited in February and March in the Bengal, Orissa, and Ganjam coast districts and neighbouring portions of the Bay, where light to moderate south-west winds set in and prevail in increasing strength.

It should be carefully noted that these south-west winds are local winds, restricted in March to a small part of the north and north-west of the Bay. Over the remainder of the Bay north-east winds continue, but are less vigorous than in January and February. With the increasing temperature and heat of the interior of India in April and May, the local sea winds in the north and north-west of the Bay intensify and also extend over an increasing area seawards as well as landwards. The increasing intensity of these winds is shown fully by the following data giving the average wind amount of the coast stations from January to June :—

Station.	Average hourly wind velocity of					
	January.	February.	March.	April.	May.	June.
Chittagong . .	3·1	3·9	5·4	6·9	6·3	6·7
Saugor Island . .	6·9	8·6	12·9	17·5	15·4	15·5
False Point . .	6·1	8·0	11·1	14·2	14·1	12·6
Gopalpur . . .	6·5	9·6	11·8	14·5	13·3	11·5

Station.	Normal mean wind direction for					
	January.	February.	March.	April.	May.	June.
Chittagong . .	N 26° W	N 43° W	S 36° W	S 9° W	S 1° E	S 24° E
Saugor Island . .	N 6° W	S 52° W	S 26° W	S 14° W	S 8° W	S 12° W
False Point . .	N 57° E	S 12° E	S 50° W	S 31° W	S 23° W	S 37° W
Gopalpur . . .	S 68° E	S 12° E	S 2° W	S 7° W	S 1° W	S 12° W

The data show most clearly the increasing strength of the local sea winds with the advance of the hot weather. It is very noteworthy that their strength is greatest in April and May, and is greater than that of the south-west monsoon winds of June, July, and August.

In March these winds extend over the Bay north of Lat. 18° N. and in April north of Lat. 14° N. South of that latitude light unsteady winds prevail,

except over the Coromandel coast district where local southerly winds (long shore winds as they are usually termed) prevail.

Whilst these changes are in progress in the north of the Bay in March and April, other changes of equal importance are initiated in the extreme south of the Bay where westerly winds set in, at first very unsteadily. These westerly winds are not true south-west monsoon winds as the belt of calms and variable winds extends over the eastern half of the Equatorial belt at this time. They appear to be mainly due to slightly lower pressure over South Sumatra and the Malay Peninsula or to an indraught from the cool sea to the heated island and peninsular areas to the east.

The region in the centre of the Bay between the area of moderate westerly winds in the south of the Bay, and of moderate to strong south-west winds in the north of the Bay is characterized by light to moderate variable winds, chiefly from northerly directions.

In May the two systems of winds in the north and south of the Bay increase in intensity and extend southwards and northwards, so that west to south-west winds prevail generally over the Bay in that month. These winds, so far as can be judged from the cloud data, are comparatively shallow and do not extend upwards more than perhaps 5,000 feet. As they blow over a sea area at a comparatively high temperature, they are, however, very damp and hence give much showery or rainy weather, more especially in the east and south of the Bay and in Burma, Bengal, and Assam. In these land areas the rainfall is chiefly due to the forced ascent of the sea winds in the Bengal and Assam Hills and usually accompanies thunderstorms. Occasionally cyclonic storms form and as conditions are favourable to their steady and prolonged development, they are occasionally of the most dangerous type, *viz.*, cyclones with a calm centre and hurricane winds.

The south-west monsoon.—The great change which initiates the south-west monsoon proper in the Bay usually occurs in the second week of June. Previous to that change, in the latter part of May and the beginning of June, south-east winds prevail in the Indian Ocean from Lat. 30° S. to the Equator and west and south-westerly winds from Lat. 2° or 3° N. to the head of the Bay of Bengal. The intermediate belt over and to the north of the Equator is an area of light, unsteady winds with showery weather, thunder squalls, etc. There is hence a clear and marked separation between the two horizontal systems in the Indian Ocean and the Bay of Bengal.

A comparatively sudden change usually occurs in the second week of June, in virtue of which the intermediate belt of light variable winds disappears and a continuous horizontal air movement is established over the whole area from Lat. 30° S. to India and Burma. There is little change in the direction of the mean winds, except in and near the Equator, where they veer rapidly from south-east through south to south-west and west-south-west in passing through the Equatorial belt.

This change is accompanied by a large rush of damp air from the Indian Ocean across the Equatorial belt into the Bay of Bengal and the Arabian Sea.

One important effect of this is to change the lower air current in the Bay from one of shallow depth (perhaps 5,000 feet) to one of great depth, probably exceeding 15,000 feet. As might be expected the vast inrush of moist air from the south of the Bay gives rise to a very large amount of irregular disturbance, more especially to much rain and frequent squalls.

This action frequently tends to localize and intensify over the centre of the, Bay with the result that the advance of this moist inrush almost invariably gives rise to a cyclonic storm of considerable to great intensity in each sea area.

This change in the character of the air movement over the Bay, ending in the establishment of the south-west monsoon over the Bay and Northern India, initiates conditions which are permanent during the next three months, *i.e.*, July, August, and September.

During this period south-west monsoon winds obtain fairly steadily in the Bay. These winds are most westerly in the south of the Bay where they average from west-south-west directions. In the north-east the direction of the lower air current is modified by the trend of the Arakan Coast and the Arakan Hills. In that part of the Bay winds range between south and south-east and are most easterly in the north-east angle of the Bay.

The south-west air current in the Bay is of very considerable height and is highly charged with aqueous vapour. The slightest disturbance in such a current tends to set up a rain squall. Amongst the exciting causes of these are, for example, the deflecting effect of a range of hills, the forced ascent of the current by a line of hills, and the meeting of two currents from different directions, as for example, the westerly air current across the Peninsula with the south-westerly current up the Bay. Hence rain squalls are of frequent occurrence in all parts of the Bay, but more especially near the Tenasserim and Arakan Coasts, the South Ceylon Coast, and the Coromandel Coast.

Another important feature of the current is the variations of its strength, more especially as these accompany variations in the rainfall over the land area in Northern India. The tendency of general heavy rain is, as it were, to exhaust the rain-giving current for some little time. The actions accompanying this are somewhat complex, and it is not necessary to describe them. As a rule, however, a period of prolonged general rain in Northern India is followed by an interval of finer weather with light showers and feeble winds.

During these intervals the conditions of fine but showery or cloudy weather are first shown in Upper India or the Gangetic Plain, and gradually extend down into Bengal and the head of the Bay. Meanwhile the monsoon winds continue in nearly full strength in the centre and south of the Bay. In a few days squally rainy weather sets in over the north of the Bay in front of these

strong monsoon winds. A cyclonic storm is usually generated which advances landwards carrying strong humid winds and heavy rain with it into the interior of India. Shortly afterwards another lull occurs and the same processes again follow.

The south-west monsoon period is hence characterized in the north of the Bay by an alternation of strong monsoon winds with squally weather, and of light to moderate winds with fine cloudy weather, and in the centre and south of the Bay by a corresponding but much smaller variation in the strength of the steady south-west winds. Small cyclonic storms form in the north of Bay at frequent intervals during the season, the chief features of which are fully described in the next chapter.

The south-west monsoon currents blow with unabated vigour in July and August and begin to show signs of decreasing strength in September. This decrease of strength is exhibited in various ways. In the first place the current does not advance so far into the interior of India as before, or in other words it gradually withdraws, first from Upper India, next from Central India, the North-Western Provinces and Bihar, and afterwards from Bengal. The withdrawal of the current from the land area of Northern India is a slow process, usually taking about a month for its completion. The pressure changes accompanying the retreat of the current are especially interesting. The withdrawal of the current accompanies an increase of pressure to the north-west and west, which is an essential part of the whole process.

In virtue of this rise of pressure the area of lowest pressure in the Indian monsoon area, which covers Sind and the Punjab during the months of June, July, and August is slowly transferred eastwards into the Gangetic Plain and then into Bengal and usually lies over Bengal in the last week or fortnight of September. These pressure changes of course accompany the slow reversal of the direction of the air movement in Northern India. Light westerly airs and calms set in over the Punjab and North-Western Provinces in the month of September and sometimes extend into Bihar before the end of the month. At the same time that the current is retreating, it is almost certainly decreasing in height, that is, the humid current gradually diminishes in elevation.

The weather conditions in the Bay in October, November, and December are determined by the continuation of the slow retreat of the south-west monsoon current. This now takes place in a southerly direction instead of an easterly direction as in September.

The area of low pressure defining the limits of the extension of the current usually lies over the north and centre of the Bay in October, over the centre and south of the Bay in November, and over the south and extreme south of the Bay in December. The winds in the region to the north of the area of lowest pressure shift round to northerly and north-easterly directions and hence the land winds from north-westerly directions, which extend westwards down the

Gangetic Plain into Bihar in the beginning of October, advance as northerly winds into Bengal and the head of the Bay in October and as north-easterly winds over the north and north-west of the Bay, and over the whole of the Bay by the third or fourth week of December, when the true north-east monsoon is fully established over the whole of the Bay of Bengal. During the period from the beginning of October to the middle or end of December, westerly or south-westerly humid winds blow over some part of the Bay, the area of course decreasing with the advance of the season.

So long as these humid winds continue to blow in the Bay, there is always a tendency to squally weather, more especially in the areas near their northern and eastern limits, and also to the concentration and development of localized squally weather into a cyclonic storm. The conditions are frequently favourable for the slow and prolonged growth of these storms, and hence they occasionally intensify into vigorous and dangerous cyclones. The favourable conditions are, as a rule, most frequently present in October and hence severe and extensive cyclones are of occasional occurrence in October and, to a somewhat less extent, in November.

Meteorological division of the year into four seasons.—The previous remarks have, it is hoped, given a connected view of the larger meteorological changes in the Bay during the year and their relations to each other. They show that the best division of the year in the Bay of Bengal from these conditions is as follows:—

1st.—From January to March or April, when north-east winds of land origin prevail over the whole or greater part of the Bay.

2nd.—May and June, during which the winds change to south-west over the Bay. The winds in May are due to local conditions. They change slightly in direction in June and strengthen considerably in the centre of the Bay, due to the change of their origin from local conditions over the Bay and India to general conditions over India, the Indian seas, and the Indian Ocean.

3rd.—July to September, when south-west winds of oceanic origin hold steadily in the Bay.

4th.—October to December, when these south-west winds of oceanic origin gradually retreat southwards and are replaced by northerly winds of land origin.

These four periods may perhaps be termed—

(1) The north-east monsoon period ;

(2) The May transition period ;

(3) The full south-west monsoon period ;

(4) The retreating south-west monsoon period.

These terms or divisions will be cited throughout the following chapters.

The following gives a brief description of the weather and currents in the

Bay, month by month, during the year. Charts, showing the pressure distribution, mean winds and currents, will be found in Plates III to XVI.

JANUARY.

Weather.—In this month pressure is usually highest in the north of the Bay and lowest at the entrance to the Bay (*i.e.*, between North Sumatra and South Ceylon). The total range of pressure over the Bay is slightly less than ·15″ giving a gradient for north-easterly winds of barely $\frac{1}{8}$. As might be expected from the conditions, winds are slightly stronger in the south than the north of the Bay. Weather is almost invariably fine with light north-easterly winds, clear or lightly clouded skies and a moderate temperature increasing southwards. Weather is occasionally squally off the East Ceylon and North Sumatra coasts due to the forced ascent of the air current produced by the mountains near these coasts. The squalls are, however, rarely severe, but are generally accompanied by much thunder and lightning.

Weather is occasionally feebly unsettled at the head of the Bay when cold weather storms or depressions are advancing eastward across Bengal. Winds then draw round to south or south-east, skies cloud over, and light showers of rain may occur. Weather is almost invariably close and sultry during the march of these storms across Bengal. They are followed by short periods of much drier and cooler weather than usual, moderate to strong northerly winds and bright, clear skies.

The temperature of the air in the shade increases from an average of 68° in the north of the Bay to an average of about 80° in the extreme south. The temperature of the sea surface water, on the other hand, ranges only between 77° in the north of the Bay and 83° in the extreme south.

Currents.—The recorded currents vary considerably in different parts of the Bay, though the main set is distinctly westerly. Round the south of Ceylon, there exists a strong and general current to the westward. This set is strongest between Lat. 4° N. and Lat. 6° N. and decreases to the southward of Lat. 4° N. There is apparently a slight outset from the Bay along the west coast of Sumatra as a south-east current, while along the Coromandel coast there are indications, though very slight ones, of a north-west current, which, in succeeding months, becomes increasingly prominent. In the north of the Bay, beween Long. 85° and Long. 90° E., the current is complicated and feeble, a north-west set existing apparently on the western side of that area, and a southerly set on the eastern side.

FEBRUARY.

Weather.—The general conditions in the Bay are similar to those of the preceding month. Pressure is highest in the north and lowest in the extreme south. The range of pressure averages about ·10″ or two-thirds of that of the month of January. North-easterly winds continue over nearly the whole area,

but they are lighter in the north and centre of the sea than in the previous month, and average barely 2·0 in force at the head of the Bay increasing southwards to force 3 in the south of the Bay.

Southerly winds are more frequent at the head of the Bay than in January. These southerly winds are due to two different actions. The first of these is the passage of cold weather depressions across Bengal, as in January. This is of occasional occurrence in seasons of normal or more protracted cold weather rains than usual in Northern India, and of heavy and prolonged snow fall in the Himalayan mountain area. The second is the earlier commencement of the hot weather than usual, following a drier and feebler cold weather than usual. The increasing heat in the interior of Bengal and in Bihar and Chota Nagpur causes the winds to shift round to southerly directions in South Bengal and Orissa and the adjacent sea area.

Weather is almost invariably fine over nearly the whole area. Squalls are of occasional occurrence near the East Ceylon and North Sumatra coasts, but they are less frequent than in January. Weather is also occasionally cloudy and muggy at the head of the Bay during the passage of cold weather storms. This type of weather is, however, less frequent than in January.

The temperature of the air in the Bay ranges from 73° in the north to 80° in the extreme south and differs little from 78° over the greater part of the centre and south of the Bay. It is hence practically unchanged over the southern half of the Bay, but increases rather rapidly in the north near the coasts of Bengal and Orissa.

The temperature of the surface water is slightly higher in the north of the Bay but unchanged over the centre and south.

Currents.—The currents in February are somewhat better defined than in January, but in general are still irregular. As in January, a general westerly current prevails in the south-west of the Bay and in the sea to the south of Ceylon, and sets with some force round the south of that island. A northerly and north-easterly current sets in during the month along the west coast of the Bay. This current, commencing in about Lat. 13° N. off Madras apparently runs up the west coast nearly as far north as Lat. 20° N., where it re-curves and returns towards the centre of the Bay as an irregular southerly set. Between Long. 88° E. and Long. 92° E. in the extreme south there are indications of a feeble and unsteady north-east current.

MARCH.

Weather.—Pressure is in March on the average of the month slightly higher in the centre than in the south and north of the Bay. The gradients at the head of the Bay and in Bengal are steeper than in February, and the south-west winds in that area hence increase considerably in strength, and also extend to an increasing distance inland and also southwards in the Bay. South

winds average 3·0 in force at the head of the Bay, and are strongest off the Orissa and South-West Bengal coasts. North-easterly winds continue in the centre and south of the Bay and are strongest in the centre of the Bay where they average 2·5 in force, decreasing to about 2·0 in the south of the Bay where they are much feebler and more unsteady than they are in February.

Fine weather prevails as a rule during the month over nearly the whole of the Bay. The air is generally very damp due to the rapid evaporation from the water surface and hence dew is usually deposited on all rapidly radiating surfaces during the night. Winds are much more variable and unsteady in the south of the Bay than in February. Squalls are of comparatively rare occurrence in March off the Ceylon and Sumatra coasts and in the Straits of Malacca.

The only area liable to squalls is the head of the Bay near the Bengal and Orissa coasts. Hot weather storms (including thunderstorms, hailstorms, nor' westers, etc.,) which form over the hills in Bengal and Orissa travel seawards and sometimes pass into the Bay. The following gives a brief general description of these storms.

The first sign of these storms is a low bank of dark clouds in the north-west, the upper outline of which has the appearance of an arch. It approaches at first slowly, and then more and more rapidly and commences with a strong gust or squall which on land raises clouds of dust. There is frequently heavy thunder and lightning followed by downpours of rain driven by the strong wind. Sometimes the winds blow with almost hurricane force and blow down trees and inflict much damage on houses, etc. These storms are sometimes accompanied with hail. The greatest velocity recorded in one of these storms at Calcutta (if the record can be relied upon) was 115 miles per hour. They rarely last more than two or three hours and are usually followed by cool clear weather during the remainder of the night.

It will hence be seen that these squalls or nor'westers may give exceedingly strong winds approaching in intensity to the hurricane winds of a cyclonic storm, and may give rise to a high sea in the north-west angle of the Bay. They rarely last for more than three or four hours and are of comparatively rare occurrence in March in the north of the Bay.

Gentle breezes between N.-W. and N. blow frequently from the land after midnight until morning on the Coromandel coast. These winds are followed by calm or faint variable airs until about noon when a south-east breeze, the long shore wind, sets in.

Temperature increases throughout the month over the whole of the Bay, more rapidly in the north than in the south. It ranges between 78° in the north-east of the Bay and 82° in the west, centre, and south.

Currents.—The most important changes in the ocean currents in March are the falling off in the strength and extent of the westerly current in the

south-west of the Bay and round the south of Ceylon and the extension southward of the northerly current, noticed in the previous month, along the western side of the Bay. This set now originates as a north-westerly current off the north-east coast of Ceylon, runs in this direction up the coast of the Peninsula as far as Negapatam where it becomes northerly and continues as far as the mouth of the Kistna, thence changing its direction with that of the coast, it runs as a north-east current right up to Orissa. In the central, southern, and eastern parts of the Bay there are no regular or general currents, and indeed over the central parts of the Bay to the northward of Lat. 10° N. a large number of observations show that there is no regular movement.

APRIL.

Weather.—During this month pressure falls slightly in the north of the Bay and rises in the south, and is on the mean of the month about a tenth of an inch higher in the south-east of the Bay than in the north-west of the Bay. The gradients are very slight, except near the Bengal and Orissa coasts. South-westerly winds prevail generally to the north of Lat. 16° N. and are strongest near the Bengal and Orissa coasts where they average 3·5 in force. Near the Arakan coast the winds blew from west or north-west. Light unsteady winds chiefly from northerly directions obtain in the centre of the Bay. They average 2·5 in force. Over the south of the Bay winds are exceptionally unsteady, winds from westerly and easterly directions alternating, the former becoming permanent before the end of the month. Winds average 2·5 in force in that area except off the West Sumatra coast where they are much stronger.

The chief features of the air movement in the Bay in this month are *firstly* the increasing strength and extension of the south-west winds in the north of the Bay, and *secondly* the weakness, unsteadiness, and variability of the winds in the southern half of the Bay (except near the Coromandel coast).

At the head of the Bay the winds show little variation during the day, but are slightly stronger during the day than the night hours. Near the Coromandel coast, the day influence is marked. The sea breeze or long shore wind begins at about noon and continues until late at night (usually about 10 P.M.) after which winds veer to south-west or west, falling off considerably in strength.

Temperature increases over the Bay during the month, more rapidly in the north than the south. It is on the mean of the month almost uniform over the whole of the Bay, averaging 84°. The temperature of the surface water is almost identical with this over the whole area.

Hot and sultry weather with light unsteady winds prevails during by far the greater part of the month over the whole area. The air is exceedingly damp and skies frequently clouded. Weather is occasionally disturbed in the south and south-east of the Bay. At the head of the Bay nor'westers are of

occasional occurrence and are felt sometimes to distances of 60 and 80 miles from land. Thunderstorms and rain squalls are of frequent occurrence in the interior of Ceylon and sometimes extend to the neighbouring sea area. Weather is also occasionally showery and squally in the south of the Andaman sea and between the Nicobars and Sumatra, more especially in the last fortnight of the month.

Currents.—The ocean currents of April are similar in many respects to those of March. There has, however, been a further and considerable falling off in the strength of the westerly current round the south of Ceylon. This current is now confined to those portions of the sea immediately contiguous to the Ceylon coast, and further to the southward, that is, between the Equator and Lat. 2° N. an easterly current begins to set in. Between Long. 86° E. and Long. 90° E. in the southern parts of the Bay, there is an exceedingly confused current. Within the Bay Proper there seems to be a feeble but fairly regular circulation of the water. On the western side of the Bay a northerly set runs parallel to the coast from Ceylon as far as Lat. 16° N. to Lat. 18° N. where it turns eastward across the head of the Bay and returns down the eastern side as a southerly current. In the centre of the Bay there appears to be, as in March, no regular current.

MAY.

Weather.—The pressure conditions in the Bay change considerably in this month and the first fortnight of June. Pressure decreases steadily and considerably in the north of the Bay and increases slightly in the south of the Bay. The mean difference of pressure between the head of the Bay and the extreme south-east is about ·16 inch, giving a mean gradient of $\frac{1}{4}$. Gradients are steepest in the north-west of the Bay where they average about 1, and decrease to about $\frac{1}{6}$ in the south of the Bay. The mean winds of the month are directly related to the pressure gradients, ranging from west-south-west in the extreme south of the Bay to south-west in the centre and north. Winds are strongest in the north-west and centre of the Bay where, on the mean of the month, they range between 3·5 and 4·0. They decrease in strength southwards and range between 3·5 and 2·5 in the south of the Bay; and are feeblest between Lat. 0° and Lat. 4° N. and Long. 88°. E and Long. 100° E. The changes in the winds which occur during the month are important, and are due to the extension northwards of the westerly winds which commence in the south of the Bay in April, and in the extension southwards of the strong south-west winds prevailing in the north and north-west of the Bay. There is a marked tendency to the occasional occurrence of light variable airs and calms in the centre of the Bay between these two wind systems, and for cyclonic storms (other conditions being favourable) to originate in this central area of calms and light variable winds. As the conditions also sometimes favour the slow and prolonged development of these disturbances, they occasionally intensify into cyclones with calm area

and hurricane winds. They are sometimes as intense and violent as the most severe cyclones of the October transition period, although as a rule they are usually of small extent. From the conditions prevailing at their inception they almost invariably form in the centre of the Bay. If they are impeded near the Andamans they usually advance north north-eastwards to Arakan or Burma (or more rarely northwards to Bengal), and if they form about midway between the Andamans and the Coromandel coast they generally advance westwards to that coast.

The mean temperature of the air in the month of May in the Bay is practically identical with that obtaining in April, averaging 84°. It is very uniform over the whole of the Bay (except of course in the immediate neighbourhood of the west coast). The temperature of the surface water ranges between 84° and 86°, and is on the whole greatest in the centre of the Bay, *i.e.*, in the area where calms and light variable airs are of most frequent occurrence.

The weather in the Bay is much more frequently disturbed in May than in April. In the south of the Bay weather is very changeable, intervals of fine weather with lightish westerly winds and moderate cloud alternating with periods of much cloud, squally weather, and heavy rain. In the south of the Andaman Sea near the Mergui Archipelago, weather is frequently squally in the beginning of May with much thunder and lightning. In the latter half of the month weather becomes more unsettled, and very squally weather with heavy rain frequently prevails for days together.

In the centre of the Bay weather is usually fine with light, unsteady winds and much cloud, and with occasionally very hot sultry weather. It is usually during such periods of hot and sultry weather, that cyclonic storms form in the belt of light winds and give rise to very stormy weather over the greater part of the Bay.

Weather in the north of the Bay is chiefly dependent upon the conditions in North-Eastern India. As a rule, south-westerly winds prevail, the strength of which depends upon the intensity of the temperature and other conditions in Bengal, Bihar, and Chota Nagpur. These winds vary in intensity considerably throughout the day. At Saugor Island and False Point they are usually strongest about 2 P.M. or 3 P.M. Nor'westers occasionally come down from the land during brief periods of unsettled weather in Bengal (usually lasting about three days). As in April these disturbances do not advance more than 80 or 100 miles seawards from land.

Occasionally very stormy weather due to the formation of cyclonic storms or cyclones prevails in the part of the Bay over which the storms advance from their place of generation to the land, and strong winds and hurricane winds may hence be experienced.

Currents.—The currents are exceedingly irregular. The westerly current of previous months round the south of Ceylon has entirely ceased, and the *long-shore* current up the western side of the Bay has almost disappeared. There

is now little or no current immediately to the south of Ceylon, but further southward between Lat. 0° and 4° N. there is an easterly current. This is met in Long. 90° E. by a westerly set which apparently prevails between Long. 90° E. and Long. 94° E. In the western half of the Bay and in the Andaman Sea the currents are generally northerly; in the north of the Bay north-easterly, but in Lat. 15° N. and Lat. 16° N. easterly and south-easterly currents are frequent and are strongest about Long. 90 °E. In the east of the Bay, easterly currents prevail to the west of the Andamans and Nicobars. This easterly current is prolonged eastwards past the Nicobars and Acheen to the entrance of the Malacca Straits.

JUNE.

Weather.—The month of June may be divided into two periods, the first usually lasting until the 7th to the 15th and the second during the remainder of the month. During the first period the weather conditions are identical with those obtaining in the second half of May. Winds are from south-west to west-south-west over the whole area and are strong in the north of the Bay, and moderate to strong in the south of the Bay, and light to moderate and unsteady in the centre of the Bay. A rapid change occurs usually in the second week of the month, practically almost simultaneous with the commencement or burst of the monsoon on the west coast. The change on the Bombay coast is so large and striking that any one can fix the day of its occurrence. Before the change, hot, sultry, dry weather with partially clouded skies, and somewhat unsteady winds (the chief variation being that of the land and sea breezes) are the characteristic features on the Bombay Coast. The change is usually ushered in by a very severe and prolonged thunderstorm and is followed by coolish but very damp weather, heavily clouded skies, frequent heavy rain, and steady, moderate to strong winds. There is no large shift in the wind direction but the character of the winds and accompanying weather completely change.

An examination of the data furnished for many years by vessels entering the ports of Bombay and Calcutta shows most clearly the nature of the change. Previously to the change the air movements in the Indian Ocean and the Indian seas are distinct and separate. In the Equatorial belt between these two areas light, variable winds and calms with much cloud and rain obtain previously to the change. These winds and weather in the Equatorial belt are due to the continuation of the south-east trades winds as a vertical or ascensional movement and not as a horizontal movement over that area.

In consequence of a gradual change of pressure conditions over the whole area, the nature of which would require more explanation than can be given here, the horizontal air movement of the south-east trades bursts across the Equatorial belt (over which the ascensional movement hence almost entirely ceases) and is continued northward over the Indian seas. The air movement of the south-east trades is much vaster and deeper than that of the previous local air movement in the Indian seas. This rapid advance of the air move-

ment of the south-east trades into the Indian seas hence changes very considerably the air movement in the Bay of Bengal. It replaces the local unsteady and shallow air movement by a general large and deep current, which brings up moisture from a sea area of upwards of ten times the extent of the Indian seas. There is hence a very large and radical change in the character of the winds and weather in the Bay in the month of June. It is then that what should be called the south-west monsoon proper is really initiated and from which it dates. Many writers state that the south-west monsoon commences at the head of the Bay in the beginning of March, and gradually works southwards and eastwards over the whole Bay by the end of May. In this they make no distinction between two air movements or classes of winds differing very largely in all respects except direction, thus not only tending to produce confusion of thought and obscurity of language, but practically suggesting an utterly erroneous explanation of the origin of the south-west monsoon or wet season of India as a whole. The previous explanation will show why the commencement of the south-west monsoon is in this book taken as occurring in June, and as due to a series of changes which commence in the south of the Bay and require several days to advance northwards to the head of the Bay.

The change which occurs in the Bay of Bengal in the second or third week of June has been fully explained above. The winds and weather in the Bay antecedent to the change are similar to those of the last fortnight in May, the chief features being moderate to strong south-west winds in the north of the Bay, unsteady and somewhat variable winds with occasional periods of calms and light airs in the centre of the Bay, and moderate west-south-west winds in the south. Weather is showery and squally in the south and south-east, fine but hot and sultry in the centre, and fine with strong winds and occasional thunder-squalls or nor'westers in the north of the Bay near the Orissa, Bengal, and Arakan coasts. The advance of the moist strong air current from the south-east trades up the Bay can be easily traced by the changes it produces. The advance is accompanied with much irregular disturbance in the south of the Bay, severe squalls with very heavy rain being the chief and most prominent feature. The irregular disturbance usually concentrates into a cyclonic storm when the advance is passing over the centre or north of the Bay. These storms generally advance west-north-westwards across Northern India and carry with them the south-west humid winds, which give a heavy downpour of rain over the storm belt, the first burst of the rains. Strong winds from the south-west generally prevail during the remainder of the month. As small cyclonic storms form in rapid succession at the Head of the Bay during the rains or south-west monsoon unsettled weather with strong winds, squalls and rain usually obtains at the Head of the Bay, and strong and fairly steady south-west winds in the centre and south of the Bay during the second half of the month.

The average difference of pressure in June between the Equatorial belt and

the Head of the Bay (a distance of 20° of latitude) is ·30″, corresponding to a mean gradient of $\frac{3}{8}$.

Skies are always more or less heavily clouded and the air very damp during the day. Showers and rain squalls are of occasional to frequent occurrence in all parts of the Bay, but more especially near the Arakan and Bengal coasts, the South Ceylon coast, and some parts of the Coromandel coast. Temperature falls slightly with the establishment of the south-west monsoon and averages about 82° for the Bay area. The mean temperature of the surface water also falls and ranges between 82° to 84°.

Currents.—To the south of Ceylon between the Equator and Lat. 4° N. there exists a slight westerly current, but to the north of Lat. 4° N. there is a distinct easterly set. After passing round the south-east of Ceylon this easterly current turns to north-east towards the centre of the Bay (Lat. 6° N. to Lat. 10° N.). Here it apparently divides, part running to the south-east towards the Sumatra coast, and part eastward to the Nicobars. Over the head of the Bay and on the eastern side, the current is generally easterly or east-north-easterly, but in the west of the Bay between Lat. 10° N. to Lat. 16° N. it is very variable. Between the Tenasserim coast and the Andamans there is a weak and unsteady northerly current.

July.

Weather.—The south-west monsoon conditions established in June over the Bay generally hold steadily through July and August. The strength of the air movement varies slightly in a slowly oscillatory manner, periods of strong winds alternating with periods of feebler winds. In the periods of strong winds there is much indraught from the Bay into Northern India and more or less heavy and frequent rain falls in Bengal and the Gangetic Plain. These periods of strong winds and heavy rain vary considerably in duration, depending upon conditions in the interior of India and also upon the general strength of the monsoon currents. Each such period is followed by a period of diminishing winds and decreasing rainfall. This change commences in the Gangetic Plain and extends eastwards to Bengal and southwards over the north of the Bay. It is usually terminated by the formation in the north of the Bay of a shallow cyclonic storm, which as a rule marches north-westward and is followed by a burst of strong monsoon winds and heavy general rain. The chief features of the weather in the Bay during the month are (1st) the variations in the strength of the monsoon currents which are feebly marked in the south of the Bay but very marked in the north, and (2nd) the succession of cyclonic storms which form in the north of the Bay during the month. The average number of these storms is about three.

The mean range of pressure between the north-west angle of the Bay and the south of the Bay is, as in June, about ·30″ and hence the mean gradient is

about $\frac{3}{8}$. Winds are, on the average, from south-west over the whole Bay except in the extreme south where the mean wind direction is from west-south-west. Winds range between 2 and 5 in force on the mean of the month and are strongest in the centre of the Bay.

The temperature conditions are practically identical with those of June.

Weather in the south and centre of the Bay is generally fine with strong winds and much cloud, but is occasionally interrupted by rain squalls. It is much more variable in the north of the Bay, where it ranges between fine weather with lightly clouded skies and stormy weather with severe westerly squalls to hurricane winds near the centres and in the south and east quadrants of the more violent cyclonic storms of the month.

Currents.—An easterly current enters the Bay to the southward of Ceylon. After passing that island it sets north-eastward, and so continues as far as the centre of the Bay. Here the current apparently divides, part continuing a more or less direct course north-eastward to the head of the Bay and the Arakan coast, and part passing eastward through the Ten-degree channel towards the Malay Peninsula.

Between Point Calimere and the mouth of the Godavari the currents are very feeble and irregular. On the coast of Orissa and Ganjam and also on the south-east coast of Ceylon there are feeble but fairly regular southerly currents. Round Acheen Head there is a very confused current, but to the westward of Sumatra, between Long. 88° E. and Long. 93° E., the set is generally towards the north.

AUGUST.

Weather.—The weather conditions in the Bay are practically identical with those of the preceding month (July). South-west monsoon winds hold with comparative steadiness over the Bay and continue to pour a vast quantity of aqueous vapour into Burma and North-Eastern India which hence receive frequent heavy rain. Pressure is unchanged in the south of the Bay, but tends on the mean of the month to increase slightly in the north of the Bay, and the average range or difference of pressure between the head and the south of the Bay is about ·25″, giving mean gradients of about $\frac{5}{16}$. Gradients are very slightly steeper in the north and centre of the Bay than in the south or at the entrance of the Bay.

Winds average 3·7 in force both at the entrance and in the north of the Bay. Over nearly the whole of the centre of the Bay except near the coasts they range between 4·0 and 5·5, and are strongest to the north and west of the Andamans. The mean strength of the winds in the north of the Bay is less than in the centre in consequence of the more frequent occurrence of moderate to light winds. The temperature of the air is slightly higher than 80° over the whole area on the mean of the month and is about 2° to 3° lower than

the temperature of the surface water which ranges between 82° and 83° over the whole area except over a part of the entrance where it averages 84°.

Winds are somewhat variable over the extreme south of the Bay, and are on the mean of the month from west south-west. Over the remainder of the Bay, except in the north-east angle, they blow with remarkable steadiness from the south-west. In the north-east angle of the Bay they chiefly blow from southerly or south-easterly directions.

Skies are more or less clouded over the whole Bay area during the month. Isolated rain squalls (that is squalls not associated with cyclonic storms) are of occasional occurrence in all parts of the Bay, but more especially off the Burma and South Ceylon coasts, and some parts of the Coromandel coast.

The strength of the south-west monsoon winds or air currents varies considerably during the month. As in July, periods of very strong winds in the Bay coincide with periods of heavy rainfall in Northern India. In the intervals between the periods of heavy rains in Northern India and of strong winds in the Bay, winds fall off at the head of the Bay ; and fine weather sets in with a decreasing sea. These periods are usually terminated by the formation of a cyclonic storm (in the north-west of the Bay to the north of Lat. 16° N.). On an average about three such storms form in August. They generally advance in a west north-west track across the Orissa coast. As a rule, the winds near the centre and to the south do not exceed 8 to 9 in force (a moderate to strong gale) but occasionally winds of force 10 to 11, approaching hurricane force, are experienced. Weather is very squally and stormy during the formation and advance of these depressions in the north of the Bay, and the south-west monsoon winds in the centre of the Bay are considerably intensified, blowing with a force ranging between 5 and 7.

Currents.—An easterly current prevails in the Equatorial sea to the south of Ceylon. After passing that island, it curves north-east and flows in that direction towards the centre of the Bay. In the extreme south of the Bay, except immediately to the south of Ceylon, there is a west to north-west current, and a little to the north between Long. 89° E. and Acheen Head a well defined northerly set. Over the centre of the Bay to the northward of Lat. 12° N. there is apparently very little movement.

A southerly current runs down the east coast of Ceylon close in shore and there is a southerly (S.S.-E. and S.S.-W.) set along the north-west coast of the Bay from the Sandheads as far as Vizagapatam.

September.

Weather.—The conditions in this month are very similar to those of July and August. Pressure continues on the mean of the month unchanged in the south of the Bay but rises slowly in the north of the Bay. The average pressure dfference between the head and the south of the Bay is about ·20″ as compared with ·25″ in August and ·30″ in July. The mean pressure gradient

over the Bay in September is $\frac{1}{4}$ as compared with $\frac{3}{8}$ in July. The gradients are nearly uniform in amount over the whole Bay. Hence the mean strength of the winds in the Bay is slightly less than for August and there is less variation in their intensity. Winds average 4·0 in force at the entrance to the Bay and 3·0 in the north of the Bay (due to occasional intervals of light unsteady northerly winds). In the centre of the Bay they range between 4·0 and 5·0 and are apparently strongest in the centre of the Bay to the west and south-west of the Andamans. Winds are somewhat less steady and more variable in direction in September than in August and July, more especially in the north-west of the Bay. They blow chiefly from west south-west in the south of the Bay, from south-west in the centre and west of the Bay, and from south or south by west at the head and in the north-east of the Bay.

There is practically no change in the temperature of the air over the Bay during the month. The mean of the month is about 79° in the Andaman sea and 80° to 82° in the Bay, temperature being slightly higher near the Coromandel Coast than elsewhere.

Skies are generally more or less clouded over the greater part of the Bay during the month. Isolated rain squalls (*i.e.*, squalls not associated with cyclonic storms) are of occasional occurrence in all parts of the Bay and are most frequent off the Arakan and Tenasserim coasts and the South Ceylon coast. The strength of the air movement varies from day to day in an irregular manner, periods of strong winds alternating with intervals of lighter winds. The intervals of lighter winds and fine weather are more prolonged than in July and August, and hence the periods of heavy rain and strong winds are shorter and less marked than in the previous two months.

The intervals of fine weather are usually terminated by the formation of cyclonic storms. They occasionally form further south than in the preceding two months, and also under exceptional circumstances may develop into cyclones of great intensity, comparable with the May and October cyclones. Hence stormy cyclonic weather is of occasional occurrence in the north and centre of the Bay. As a rule, from two to three storms form in the Bay during the month. Winds generally do not exceed force 8 and 9 near and to the south of the centre, but hurricane winds of force 12 have been experienced.

Currents.—A southerly (south-west and south-east) or long-shore current prevails down a large part of the western side of the Bay close in shore. On the Orissa and Ganjam coasts it is very decided. This current is less strongly marked on the Coromandel Coast, but re-appears very prominently off the east coast of Ceylon. Over the centre and a great part of the south of the Bay, as well as over a large part of the Equatorial sea to the south, the set of the water is almost entirely to the eastward ; but there are two exceptions, a distinct north-east current prevailing in the upper part of the Bay in Long. 90° E. and a well-defined south-east current to the westward of Sumatra. Off Acheen Head the current is very confused. To the south of

Ceylon between Lat. 3° N. and Lat. 6° N. there is a moderate easterly current, but further to the southward between the Equator and Lat. 3° N. the set is also confused.

OCTOBER.

Weather.—The last week of September and the month of October witness a large change in the pressure and other meteorological conditions in India. Pressure increases rapidly in North-Western India and moderately in North-East India and the north of the Peninsula and falls slightly in the south of the Bay. The effect of these changes is to give almost uniform pressure over the whole of India with a tendency to slightly lower pressure in the centre of the Bay than elsewhere. These important changes accompany the withdrawal of the moist south-west monsoon currents from Northern and Central India. This change commences in Upper India (*i. e.*, the Punjab, Sind, and Rajputana) where the rains usually cease in the third or fourth week of September when light, variable winds with clear skies and dry weather set in. Somewhat later, in the beginning of October, the rains usually cease in the Gangetic Plain and Central India and fine, dry weather sets in, extending southwards and eastwards from the Punjab. Showery weather continues for some days longer in North-Eastern India and the Central Provinces, but in the third week of the month the moist winds usually withdraw from these Provinces. Damp, muggy weather with very light unsteady winds prevails in these two areas during the remainder of the month. The change described above is hence comparatively slow and gradual, and each stage of the change is marked by a corresponding change in the pressure conditions. The final result in the third week of October is to give almost uniform pressure over the Bay with a very slight tendency to low pressure in the centre of the Bay. These pressure conditions accompany the prevalence of very light airs and calms over the centre of the Bay. Westerly winds continue over the south and south-east of the Bay, whilst north-east winds tend to set in over the north-west angle of the Bay. The continuance of the damp south-westerly to westerly winds over a part of the Bay forms one of the conditions necessary for the formation of cyclonic storms or cyclones and the uniformity of the pressure conditions favours their slow growth into large and intense cyclones. The weather in the Bay during the month is hence more variable and treacherous than in any other month of the year. The finest weather frequently prevails for considerable periods in the north and centre of the Bay. Occasionally, however, the largest and fiercest cyclones form and march across it, giving hurricane winds and a dangerous sea.

Winds are exceedingly variable in the north and centre of the Bay and show no predominant direction. They usually range between 0 and 2 in force during the fine weather of the month. To the south of Lat. 12° N. winds are chiefly from south-west or west-south-west and average 3 in force over the south of the Bay and 4 to the south of Ceylon.

The mean temperature of the air in October in the Bay is practically the same as in September. It averages about 79° in the Andaman Sea and between 80° and 82° in the Bay. The temperature of the surface water is slightly greater (about 1°) in the north of the Bay averaging 81°.

The preceding remarks indicate the general character of the weather in the Bay during the month.

During the greater part of the month weather is fine with light winds and clear skies or passing clouds in the north of the Bay. Occasionally weather is disturbed or stormy due to the influence or passage of a cyclonic storm which has formed in the centre of the Bay. Weather is hence very variable during the month over the north of the Bay. There is a marked tendency to the occurrence of very light airs and calms with cloudy, showery weather, with prolonged intervals of fine, clear weather in the centre and north of the Bay. As a rule from one to two storms form in this area during the month and these storms occasionally give cyclonic weather of the most violent kind. Over the south of the Bay the south-west winds of the south-west monsoon continue to blow with more or less regularity. They are usually feeble (not exceeding force 3) when fine weather prevails, but invariably intensify when squally or stormy weather prevails in the centre of the Bay. Weather is then frequently squally in the south of the Bay with heavy cloud and a high swell.

Currents.—The currents of the Bay are, on the whole, similar to those of September. Over the head of the Bay and on the coast of Orissa and the Northern Circars, the currents are more westerly than in the preceding month; but on the Coromandel coast they are steadily southerly, and on the east coast of Ceylon, are south south-easterly, parallel to the coast. On the south coast there is a slight set to the westward. In the southern portion of the Bay, below Lat. 7° N., there is a general easterly current, but over the Bay proper, with the exception of the long-shore current, noticed above, the currents are a good deal confused, and, in the centre, *i.e.*, between Long. 85° E. and Long. 90° E. and Lat. 7° N. and Lat. 14° N. there is no regular movement. The currents may be briefly described as follows:—A westerly current in the north-east of the Bay; a southerly current along the Coromandel coast; a south south-east current off the east of Ceylon, and a general easterly current over the seas in the south.

November.

Weather.—The most important feature of the month is the increasing weakness of the south-west monsoon current and winds over the south of the Bay. Pressure continues to rise in the north and centre of the Bay, and on the mean of the month pressure is about a twentieth of an inch higher in the north than in the centre of the Bay. Pressure is usually lowest in a belt stretching across from the Coromandel and Ceylon coasts to the Nicobars. North-east winds, light to moderate in force, prevail fairly steadily throughout

the month in the north and greater part of the centre of the Bay. Light variable unsteady winds, as a rule, obtain in the area of lowest pressure between the Andaman and the Ceylon and South Coromandel coasts, whilst over the entrance to the Bay moderate westerly winds generally prevail. The wind force in the north and centre of the Bay ranges between 3 and 4, and in the central area of lowest pressure between 2·5 and 3·2. Over the entrance to the Bay they average 3·0 in force. Fine weather with clear skies generally prevails over the northern half of the Bay. Weather is frequently showery to squally in the south of the Bay where the damp westerly winds of the retreating south-west monsoon still blow. Cyclonic storms tend to form in the belt of variable winds and hence considerably further south than in October. The conditions are less favourable for their full and slow development, and hence they do not attain the intensity or extent of the most severe October cyclones. They, however, invariably give very stormy weather in the south-west and centre of the Bay, and winds are occasionally of hurricane force near their centres.

Temperature now falls rather rapidly in the north of the Bay and the mean temperature of the air during the month ranges between 75° in the north of the Bay and 80° near the Ceylon coast.

Currents.—A westerly current sets sometimes across the head of the Bay and is also experienced along the Orissa and Ganjam coasts as well as to a considerable distance out to sea. To the south of Lat. 16° N., on the western side of the Bay, the set becomes southerly and off Madras runs strongly to south. Throughout the period from October to February, the current is southerly on this coast, but it reaches its maximum strength in November, when it sometimes has a velocity of nearly 4 miles per hour. A strong southerly current also sets along the east coast of Ceylon and continues past the Basses; but to the westward of these rocks the current changes its direction with the coast line and flows as a westerly current round the south of Ceylon. Some little distance to the eastward of Ceylon, between Long. 84° E. and Long. 86° E., the set of the water is often northerly, and in the latitude of Madras, in the same meridian, it is generally westerly. Off Acheen Head, and indeed over a large part of the eastern half of the Bay, the current is very feeble and variable.

DECEMBER.

Weather.—The month usually witnesses the complete and final withdrawal of the south-west monsoon currents from the south of the Bay. The pressure changes are the continuation of those of the previous month. Pressure continues to increase in the centre and north of the Bay, and on the mean of the month there is a pressure difference of about ·15″ between the head of the Bay and the extreme south, corresponding to the gradient of $\frac{3}{16}$ for northerly winds. The area of lowest pressure shifts southwards and passes out of the

Bay into the Equatorial belt usually in the third or fourth week of the month. Steady north-easterly winds prevail during the month over the north and centre of the Bay. These winds are comparatively feeble at the head of the Bay (averaging 2·5 in force), but increase in strength southwards to about Lat. 12° N. off the Coromandel coast, where they average 4·0 in force. Winds are light and very unsteady between the Equator and Lat. 6° N., but show a marked tendency to northerly directions.

Weather is usually cloudy, with occasional showers or squalls, in the extreme south of the Bay. Occasionally but much less frequently than in November, cyclonic storms form in the area of low pressure in the south of the Bay. Sometimes these storms are imperfectly developed as cyclonic circulations, but are remarkable for the heavy rain and squally weather they give. They almost invariably cross the South Coromandel coast, or in the case of the imperfectly developed storms, the East Ceylon coast. They give squally weather with heavy rain, but the winds as a rule do not rise above force 8 to 9 near their centres.

Temperature falls rapidly during the month in the north of the Bay. It ranges between a mean of 63° at the head of the Bay and 75° in the 16th parallel of latitude, and between 75° and 80° between the 16th parallel and the entrance to the Bay.

Currents.—There is a general set to south-west throughout the more northern districts of the Bay. This current commences on the Arakan coast and crosses the Bay to the coasts of Orissa and the Northern Circars. On the Coromandel coast, it turns south, but runs with less velocity than in November. To the east of Point Calimere, between Long. 82° E. and Long. 84° E., it sets to west or south-west; but round Ceylon, within 50 miles of the coast, as, in November, it sets along the coast running to south-south-east and south, then rounding the island to south-west and west. This current is stronger than in November and at times runs at a rate of between 2 and 3 miles an hour. To the south of Ceylon, the westerly current extends almost down to the Equator. Further eastward, the movement of the water in the extreme south of the Bay is less regular. In the Andaman Sea, the currents are chiefly to north-west, but to the west of the Bay Islands the set changes to west across the Bay, coalescing with the southerly movement on the western side.

CHAPTER III.

PHENOMENA OF CYCLONIC STORMS AND CYCLONES IN THE BAY OF BENGAL CHIEFLY CONSIDERED AS STORM INDICATIONS.

Preliminary Remarks on Cyclonic Storms.—In the preceding chapter, the more important principles and facts of the science of meteorology have been explained for the use of mariners, so that they may use the meteorological instruments generally found on board to greater advantage than hitherto when navigating the Bay of Bengal, and also may be enabled to understand weather charts and obtain, from an inspection of them, information of the general character of the weather over a large area. In the present chapter we deal with the chief object of the book, *viz.*, the more important features and peculiarities of cyclonic storms in the Bay of Bengal, and more especially those features which can be observed by a sailor and employed as indications to determine the probable character, position, and track of any cyclonic storm he may encounter when navigating that sea.

It has been explained in the preceding chapter what is meant by a barometric depression and what by a cyclonic circulation. We have also stated that in an area of barometric depression (that is, an area in which the barometer stands lower than in neighbouring districts and gradually rises outward from some central position in all directions), the air moves invariably in a particular direction and manner round this central position, and that such an air motion is technically called a cyclonic circulation. Frequently, the air motion in such a circulation is feeble and winds light. There is, however, under favourable conditions in the Bay of Bengal, a marked tendency for a cyclonic circulation when established to become stronger and more vigorous; when this is the case, the cyclonic circulation may gradually develop into a cyclonic storm. *All large storms in the Bay of Bengal are cyclonic circulations: all cyclonic storms are of more or less gradual growth and commence as feeble circulations.* Hence cyclonic circulations in the Bay are of very varying strength or intensity, as well as of magnitude. It is of course not possible to draw hard-and-fast lines in such matters. Hence cyclonic circulations and cyclonic storms differ in two elements—extent and intensity. In the area covered by a cyclonic storm, the winds increase in force from the outer limit to the centre or the central calm area (if there be one): over a portion of this area nearest the centre, winds of force 7 and 8 upwards to 12 may prevail. This inner area forms the storm area of strong to dangerous winds. The size, or greatest width, of this area gives a rough measure of the magnitude or extent of the storm.

The intensity is best and most easily measured by the depth to which the

barometer at the centre falls. The simplest standard of reference is the ordinary or normal height of the barometer at the time. The difference below this and the actual height of the barometer at the centre gives a rough practical measure of the intensity of the storm.

The intensity of cyclonic storms appears to be, to a very considerable extent, independent of their magnitude. Thus, it is not only possible to have a storm of considerable extent but of very feeble intensity, but it is also possible to have a storm of small extent, and of great and even extraordinary intensity. The most intense storm in the Bay of Bengal on record is the False Point cyclone of September 1885, in which the barometer at the centre was approximately 2½ inches lower than usual at that period of the year. The largest storm, as well as the most intense storms in the Bay was the Backergunge cyclone of October 1876.

The storm area in the case of the largest and most intense cyclones may be divided into two portions : an outer and an inner storm area. In the outer storm area, the barometer falls slowly and to a moderate extent, and the winds are of force ranging from 6 to 9 or 10, the strongest winds being experienced in the squalls. In the inner storm area the barometer falls with excessive rapidity from the outer edge to the central area (which is in the Bay of Bengal an area of calms). The baric gradients are hence excessively steep, the winds of hurricane force, the shifts of wind rapid, and the sea very high, confused, and dangerous. The most remarkable feature of this inner storm area is a small central area, usually known as the calm centre, or bull's eye of the storm, in which there is little or no wind and cloud, the sun or stars usually visible through a thin veil of mist, and the sea pyramidal and boiling like a cauldron.

The reader should hence remember that in the most vigorous cyclones of the Bay of Bengal the storm forms only a portion (the inner portion) of a cyclonic circulation. In the outer portion of the cyclonic circulation, the winds are governed by the indraught to the storm area, but are of moderate force, and not of sufficient intensity to be considered as stormy winds. The inner portion of such a cyclonic circulation includes :—

(1) The outer storm area in which winds of force 6 to 9 prevail.

(2) The inner storm area in which winds of force 10 to 12 prevail.

(3) The calm central area.

The ratios of the magnitude of these differ very greatly in different storms.

By far the larger proportion of cyclonic storms which occur in the Bay are of small extent and moderate intensity. In these storms there is no calm centre, and rarely an inner area of hurricane winds. The weather, sea, and winds in these storms are such as occur in the outer storm area of the severe and dangerous cyclones described in the preceding paragraph. Cyclonic storms of sufficient extent and intensity to be dangerous occur in the Bay only during the period that south-west winds are blowing more or less steadily over the

entrance and south of the Bay—that is, from the beginning or middle of April to the end of December. This period will for convenience be called the "cyclone season." Cyclonic storms may occur in the Bay at any time during this period. The character of the storms varies to some extent during this period, being dependent on the general weather conditions prevailing at the time of their origin.

As is well known to sailors, during the months of January and February, steady and moderate north-east winds and fine clear weather usually prevail in the Bay. These north-east winds of the north-east monsoon are analogous to the corresponding winds of the north-east trades. In the beginning of March, with the rapid increase of temperature in Northern and Central India, local sea-winds commence at the head of the Bay and strengthen. These winds back down the Bay to some extent in April. During this period of gradual change from the prevalence of dry land winds in the interior to the setting in of the humid winds of the south-west monsoon period, (which may be termed the May transition period,) the north-east winds in the Bay become feebler and are replaced by light, unsteady, variable winds in the centre of the Bay in April and May. This continues until the latter part of May or beginning of June when, after one or two preliminary feeble efforts, the true south-west winds of the south-west monsoon advance rapidly up the Bay, and shortly afterwards penetrate into Burma, Bengal, and gradually into Upper India.

This change introduces the south-west monsoon winds and rains proper into India, which last until about the middle or end of September. After this the rain-giving winds retreat and tend to back down the Gangetic Plain and the Bay. The retreat of these winds in the Bay, unlike their advance, is a very slow process and continues until about the end of December. In consequence of the peculiar conditions then prevailing in the Bay, the south-west winds still blowing over the south of the Bay and curve through south, south-east and east, and thus reach the Coromandel coast as north-east damp winds, and give for a period of about two months occasional moderate to heavy rainfall to Southern India. The commencement of these rains in October in Southern India is usually termed the beginning of the north-east monsoon, but the rains ought really to be thought of and called "late or retreating south-west monsoon rains." This period of slow change from the prevalence of the south-west monsoon over the whole of India to its final retreat from the Bay is, for convenience, called the October transition period. The division of the year described above is hence as follows:—

(*a*) North-east monsoon period, from the 1st January to the middle of March, characterized by fine weather and absence of cyclonic storms in the Bay.

(*b*) May transition period, extending from the 15th March to the beginning of June, characterized by the extension of south-west winds

in the north and south of Bay, and terminated by the general advance and establishment of the south-west monsoon.

(*c*) South-west monsoon period, from the 1st June to the 15th of September, or period of general rain in India due to the prevalence of steady south-west winds over the whole of the Bay, the Arabian Sea, and India.

(*d*) October transition period, from the 15th of September to the end of December, marked by decay and retreat of the south-west current in Bay, and terminated by its final disappearance.

The experience of many years has shown that during the south-west monsoon period proper, *i.e.*, from 1st June to 15th of September, there is a rapid succession of cyclonic storms of moderate extent and small intensity. These are the storms of the rains proper. In many cases they form quite close to the coast of the Sunderbuns or occasionally in South Bengal, and their only prominent feature which comes to the notice of sailors is the very strong westerly winds which blow in their southern quadrant near the head of the Bay. Hence they are sometimes described as westerly gales, but it should be remembered that they are in all respects cyclonic storms.

During the May and October transition periods, storms on the whole occur less frequently than during the rains proper. The majority of the storms of these two periods are of moderate extent and intensity, but occasionally they develop into storms of great extent or intensity. A rough calculation, based on the experience of the past twenty years, shows that about one out of three cyclonic storms which occur during these periods, is a fierce and dangerous cyclone with an inner storm area of hurricane winds and a calm centre.

There is hence a very marked distinction between the smaller cyclonic storms, which are of frequent occurrence during the whole cyclone season, and more especially during the rains proper, and the intense cyclones which are of very occasional occurrence and appear only during the transition periods.

It has already been pointed out that cyclonic storms form gradually, and if conditions are favourable increase in intensity until they become fierce and dangerous storms.

The order of growth of a cyclone is—

(1) Squally weather, with irregular winds.

(2) Squally weather, with cyclonic circulation of moderate intensity.

(3) Intensification of the cyclonic circulation, commencement of hurricane winds near the centre, and the development of calm centre.

We now proceed to give a brief discussion, with illustrations from recent information contained in the copies of the meteorological logs of vessels sent in to the Calcutta Meteorological Office, of some of the more important phenomena of cyclones, more especially those which can be used as indications of their position and line of march.

This is followed by a detailed account of cyclone distribution and of tracks as dependent upon the weather conditions of the period, and, finally, by a full discussion of the relations of the wind directions in different parts of the storm area to the bearing of the storm centre. In the concluding summary it is shown how from any given indications the existence of a cyclonic storm can be frequently judged, and from wind and other observations its probable bearing and course can be inferred.

Character of the weather and sea disturbance in the smaller storms of the rains proper.—The character of the smaller cyclonic storms of the rains had been to a certain extent already described. They may occur at any time between the beginning or middle of June and the middle or end of September. The barometer at the centre is rarely more than two or three-tenths of an inch below the normal pressure of the period. Judging from the experience of the past twenty years they very rarely, ever have a well-marked calm centre. The winds to the north, north-west and west of the centre of wind convergence are comparatively feeble. For example, in the storm of July 1883, when hurricane winds of force 11 and 12 were blowing at the Sandheads, over which the centre was slowly drifting, the force of the northerly winds at Saugor Island, 50 miles to the north, at the same time, was only 3 to 4. In these small storms strong cyclonic winds are only experienced in the great majority of cases in the south and east quadrants. Hence the cyclonic nature of these storms was for many years overlooked and they were regarded simply as westerly gales. This was of course due to the fact that they formed near the head of the Bay, and hence the only marked feature of the storm which came under the notice of sailors was the strong westerly and south-westerly winds which prevailed in the centre and north of the Bay during the storm and for some time after its passage inland. They are, notwithstanding, true cyclonic storms with a centre of indraught, exactly as is the case in the cyclones of October and November, and the same rules for the determination of the centre and line of march apply as in the case of other cyclonic storms in the Bay. As the barometric depression at the centre is small and the storms are of small extent, they are never accompanied by storm-waves, such as frequently cause in the case of the October cyclones so much destruction of property and loss of life in the low-lying lands at the head of the Bay.

The sailor in the Bay of Bengal should hence realize fully the cyclonic nature of these storms. As they usually form near the head of the Bay and pass in the great majority of cases across the Orissa coast, they are occasionally very trying to vessels proceeding from the Hooghly southwards. The chief indication of the formation of one of these storms on the Orissa and South-West Bengal coasts is the suspension of the ordinary south-west monsoon winds and the setting in of north-east or east winds (described in pages 121-122), and of comparatively fine and dry weather in the midst of the rainy season.

If a vessel leaves the port of Calcutta and proceeds down the river during

the months of June, July, August or September, while these unusual conditions prevail, *viz.*, light north-east or variable winds with fine, bright, sultry and comparatively dry weather, the sailor may be almost certain that there is dirty weather at the head of the Bay. It may be no more than squally weather, but it may be a severe storm of the rains. It should, however, be remembered that as these storms are small, they may give rise to more rapid shifts of wind than the larger storms of the October period. The wind and sea in the southern and eastern quadrants are frequently almost as dangerous and trying as in the larger cyclones of the October period. Hence the captain of a vessel about to go to sea from the Hooghly in such suspiciously fine weather in the rainy months should hesitate to proceed unless he is fully prepared to weather a storm. The storm may be a feeble one, but, on the other hand, it may be one from which he may find it difficult to escape without damage to his vessel if it overtakes him in the confined north-west angle of the Bay.

The following descriptions of the weather experienced in these storms during recent years are extracted from the logs of vessels sent in to the Meteorological Office, and will show that the weather and sea in such storms may be of cyclonic character and intensity, and very dangerous.

The log of the ship *Craigburn* thus describes the weather experienced in a small storm at the head of the Bay on the 15th June 1886 :—

"10 A.M.—Terrific squalls, with terrible confused sea. NOON.—Gale apparently increasing, if possible. Squalls appalling, with terrible lightning and occasional peals of thunder. Sea running mountains high in all directions."

The log of the P. S. *Cassandra* describes the weather she had in the same storm as follows :—

"Vessel commenced driving on account of the terrific sea and very heavy squalls in rapid succession."

The log of the ship *Airlie* describes the same storm as follows :—

"8 P.M.—Blowing fiercer than ever, the wind roaring like heavy thunder. The squalls were so heavy and accompanied with such blinding rain that it was an impossibility to see the fore part of the ship. 11 P.M.—I think that this is the time it blew hardest. You could scarcely move on deck, as the cyclone blew with such fearful force and the squalls were really something awful. The rain seemed to come down in one solid body."

The following gives an account of the weather as experienced on board the floating light-vessel *Canopus* during a small storm in the fourth week of September 1887 :—

"*September 23rd.*—8 P.M.—Rapid succession of blinding and very heavy rain squalls, attended with violent lightning and thunder. 10 P.M.—Blowing a very heavy gale, with almost continuous heavy rain, squalls and vivid lightning and thunder. MIDNIGHT.—Wind still increasing, accompanied by most terrific rain, squalls of full cyclonic force and vivid lightning. Nasty cross sea getting up.

"*24th.*—Commenced with hard gale, accompanied by most terrific heavy rain ; squalls of full cyclonic force and most vivid lightning * * * * About 10 A.M. it blew with most terrific force, accompanied by most blinding heavy rain and very vivid lightning, and the sea became a perfect seething mass of foam."

The following gives descriptions of the weather experienced during a small but severe storm at the head of the Bay in June 1883:—

The log of the ship *British Princess* runs thus—

"*28th June 1883.*—4 A.M.—Heavy rain, vivid lightning with thunder, high confused sea. 8 A.M.—Heavy squall with torrents of rain. NOON.—Moderate gale, high confused sea. 4 P.M.—Fresh gale, high sea and heavy rain. 8 P.M.—Heavy squalls, torrents of rain, high sea. MIDNIGHT.—Furious squalls, torrents of rain and high sea."

The log of the British India Steamer *Commilla* gives a fuller and even more impressive account of the weather during the same storm :—

"*28th June 1883.*—4 A M.—Very high sea from south and south-west. 8 A.M.—Breeze very variable in force, with very hard squalls from south-south-west and rain. NOON.—Very high sea running from south-south-west. 4 P.M.—Very high sea from south-west, and hard squalls from south-south-west. 6 P.M.—Breeze very unsettled and hauling to north-west at times. 6-30 P.M.—Very heavy wind and rain, tremendous sea from south-south-west and south-west. 7-30 P.M.—Terrific sea carried away starboard cutter. 8 P.M.—Terrific squalls from south-west and very high sea. New jib and staysail split."

"*29th June 1883.*—4 A.M.—Terrific storm, continual rain and furious squalls. 8 A.M.—Squalls of hurricane force ; mountainous sea. NOON.—Very high and dangerous sea running; both anchors lifted out of catch-hooks, breaking one stock. 4 P.M.—* * * Violent squalls from south-west. 8 P.M.—Sky overhead clearing at times ; very dark, wild, squally weather ; very heavy rain in the squalls."

The log of the ship *Pemba* describes the same storm briefly as follows :—

"*29th June 1883.*—Fierce gale, with high, irregular sea, and hard squalls, blowing with hurricane violence. * * * * Sea breaking over the ship fore and aft."

The following is a description of the weather experienced on board the *Canopus* during a storm in the fourth week of August 1888:—

"*August 23rd.*—Between midnight and 4 A.M. the wind again increased to a hard gale, attended with blinding terrific rain squalls, and very high confused southerly and west-south-west seas, which became heavier as the wind increased. At 8 A.M. the wind was blowing with full cyclonic force, the sea one mass of foam, between the salt sprays and heavy blinding rain the fore part of the vessel was not visible. This lasted up to 2 P.M. Between 2 and 10 P.M. there was a slight lull in the gale, but the sea kept up."

The following extracts from the logs of the Pilot Vessels *Fame*, *Sarsuti*, and the Floating Light Vessel *Canopus* that encountered the cyclonic storm of the 8th to 13th of June 1892 are given below:—

"*Fame.*—At 5 A.M. of the 9th it was blowing a hard gale from east and every thing was made ready for a cyclone. The wind remained at east, and the vessel's head south up to 4 P.M. From 8 A.M. to 4 P.M. the wind was blowing with hurricane force with a calm three times; the first and second time the storm recurved and the wind came from east again, and on the third time at 4 P.M. the wind came from north-east and veered through north and north-west to west at 8 P.M. and west-south-west at 10 P.M. It blew with hurricane force from 4 P.M. on the 9th to 2 A.M. of the 10th."

"*Sarsuti.*—About 5-30 P.M. of the 9th the westerly burst was heralded by a tremendous peal of thunder, which reverberated through the dark cloud masses, and shook our little vessel. The wind sprang in force to a hurricane at west and west-south-west. At 10 P.M. the glass had risen to 28·98″, with heavy squalls and rain. At midnight, barometer 29·09″, and wind south-west by west, force 12. The sea was lashed by heavy gusts, and sky and sea all round were lit up by brilliant lightning flashes which revealed a scene of the wildest turmoil. Rain fell copiously in the squalls. At 2 A.M. the barometer was 29·20″, and although the glass had risen a little, still the wind howled and whistled aloft in the rigging, and the squalls were as fierce as ever. But this rise of the glass, though slow like its fall, showed that the worst of the storm was over."

"*Canopus.*—The 9th commenced with a brisk easterly gale but increasing, and by 8 A.M. it was blowing a hard gale accompanied by passing rain squalls, wind steady at east. By evening the southerly sea rose to a terrible height. This weather lasted till 10 P.M. when there was a lull for a few minutes and at 10-30 P.M. the wind shifted suddenly to the south-west and commenced to blow with terrible force from that hour up to 4 A.M. of the 10th accompanied with heavy thunder and lightining and heavy rain and a most terrific confused sea."

The following shows the character of the weather experienced by F. L. V. *Hesperus* during a storm of the rains at the head of the Bay on the 24th July 1894:—

"1 A.M.—Wind freshening fast and sea rising. 5 A.M.—Whole gale, squalls, heavy rain, and high sea. 1 P.M.—Full cyclonic squalls till dusk. Sea blown down by wind. Rain in solid sheets. Sea risen like magic. Every thing invisible beyond a few yards from ship, and afternoon more like night than day so that the midship part of ship could not be seen standing from aft. After sunset rain fell off in quantity and squalls less fierce, although they were yet of violent cyclonic force."

The following is the account of the weather as experienced by the F. L. V. *Torch* at the Eastern Channel during a storm of the rains at the head of the Bay on the 28th June 1895:—

"At 10 A.M. the wind chopped into the south in a heavy rain squall and increased in force very rapidly; by noon it was blowing a fierce gale, force 10, with continuous, blinding rain squalls, and sea very high and confused. This lasted up to 4 P.M., when the wind abated a little, but not the sea. From 4 P.M. on the 28th to 4 A.M. on the 29th it blew steadily a fresh gale from south-south-west with continuous heavy rain squalls and very high confused sea."

The following gives a description of the weather experienced by the ship *Rhine* during a small storm at the head of the Bay on the 27th June 1896:—

"2 A.M.—Wind blowing with increased violence with a perfect deluge of rain; sea in wild state.

10 A.M.—Wind not so violent.

NOON.—Terrific gale with squalls of hurricane force, heavy rain; sea in a very confused state.

1 P.M.—Blowing a terrific gale accompanied with heavy rain and squalls of terrific violence. Sea in a very confused state, causing ship to roll and labour in a most violent manner."

The following gives an account of the weather experienced on board the floating light vessel at the Mutlah station during a storm at the head of the Bay on the 26th July 1896:—

"From 13 to 16 hours the sea was a boiling pot, and the confused swell very high. A very curious sight was this sea at this time; in fact what with the darkness caused by the fearful rain and this sea one could not really help but wonder at it. Description is out of the question for me. The current was running south about 5 knots per hour during this time.

"From 19 to 22 hours, prolonged squalls at short intervals and much lightning and heavy thunder. One squall at 21 hours was of full hurricane force, after which the rain ceased and sky cleared; also the thunder and lightning ceased. From 20 to 22 hours I think it rained in a solid mass. The rainfall during this time prevented cloud observations. A fearful sea was running at this time."

The log of the ship F. L. V. *Torch* describes the same storm as follows:—

"8 A.M.—Blowing a heavy gale from the north-west; southerly swell very heavy, south-west sea high and confused, and blinding rain coming down in continuous torrents.

NOON.—Wind and weather the same.

SUNSET.—Wind and weather the same. High south swell and confused sea more quick and toppy, looking very wild to the north, west, and southward.

8 P.M.—Much lightning to the south. Wind veered from north-west to west and increased in force to 10. Thunder and lightning continuous and the rain falling in torrents, this weather lasting till midnight."

It is not necessary to multiply these descriptions, as the previous extracts have shown that very stormy dangerous weather and winds of hurricane force may be experienced in these small storms.

Even more dangerous weather occurs in the case of the small, but very intense cyclones that occasionally form in September shortly before the commencement of the October transition period and advance to the north-west angle of the Bay. The False Point cyclone of September 1887 is a typical example.

The following extracts from the logs of vessels that encountered the False Point cyclone of September 1885 are given in illustration. This was a very small storm, which in all its more important features resembled the fierce October cyclones that occasionally occur, but which happened very early in the season.

Ship *Governor Wilmot*, 20th September, in Lat. 14° 45′ N., and Long. 92° 20′ E.—

"4 A.M.—Whole gale; furled foresail and fore and main topsails; * * * blowing very hard. 8 A.M.—Regular hurricane; sky black; thick clouds, low; sea rough, breaking on board; constant heavy rain. Barometer very low. Sky thick and black; at noon more like night."

Ship *Kunt Alfasson*, 21st September, in Lat. 17° 04′ N., Long. 87° 04′ E.—

"* * * Later on the wind continually freshened to a terrific gale * * * * * Rain pouring down continually in immense quantity all the time without ceasing, and the gale blowing in terrific puffs; * * * * the sea very turbulent and high, and the barometer continually going down."

Ship *Quang Tung*, September 21st, in Lat. 19° 53′ N., Long. 89° 10′ E.—

"9-45 A.M.—Wind and sea rapidly increasing; very heavy south-easterly sea. NOON.—Very heavy sea. 3 P.M.—Very hard squalls from the eastward with a very heavy sea. 4 P.M.—A heavy sea struck the port forward sponson house, smashing it completely in, washing away engineer's bath-room, etc., 8 P.M.—Very hard squalls from the eastward; heavy sea and swell. MIDNIGHT.—Very heavy confused sea."

Ship *Calcutta*, 21st September, in Lat. 16° 50′ N., Long. 89° 32′ E.—

"The sea all this time seemed to come from all quarters. Heavy spray came on board first from one place and then another."

Ship *Clan MacIntosh*, September 21st in Lat. 19° 35′ N., Long. 86° 47′ E.—

"MIDNIGHT.—Strong gale, with terrific squalls and torrents of rain and wind blowing at times with hurricane force. Wild confused sea."

Ship *Britannia*, 21st September, at noon, in Lat. 20° 21′ N., Long. 87° 25′ E.—

"MIDNIGHT.—Blowing a hurricane, much lightning. From 1 to 3 A.M. it blew in terrific squalls, and * * * so much rain fell we could not see the masts and yards."

Character of winds to the north and west of cyclonic storms in the Bay of Bengal during storms of the rains proper.—It has been pointed out more than once that the most important feature in cyclonic storms is the strong south-west moist winds which feed into them. Hence it becomes important to know the chief features of the south-west monsoon winds, as it is probable that cyclones may in part at least depend upon changes in that current. The observations of recent years, both on land and at sea, prove that the south-west monsoon is much more variable than was formerly supposed. It is not a steady air-current like the south-east trades in the Indian or Pacific Ocean. It appears, on the contrary, to go through a series of pulsations. During the first part of each of these periods it advances in force into the interior of India and gives general rain for some time. Afterwards it appears to weaken and backs down the Gangetic Plain, and the strong rain-giving winds in Northern India are replaced for a short time by light unsteady winds. This is followed by another advance of monsoon rain-giving winds, and so on throughout the whole monsoon season. These variations of strength and alterations of advance and withdrawal form the most conspicuous and one of the most important features of the south-west monsoon in Northern India.

It is found that almost without exception during the rains proper, all the cyclonic storms that are generated during the period between the 15th of June and 15th of September form in the intervals between the partial retreats and advances of the monsoon current. They hence appear to commence to form in front of an advancing rush of moist winds, and, as they march across the coast into the interior, they carry the damp winds and rain with them. They are hence one cause of the very unequal way in which the rains are frequently distributed during the south-west monsoon in Northern India, as these storms draw the rain away from other districts to distribute it in large amounts over the narrow belt along which they advance. These storms of the rains, as has been pointed out more fully in page 115, are almost invariably of small intensity, as measured by the barometric depression, and generally give moderate cyclonic winds, although occasionally (in about one storm out of five or six) they are attended with winds or squalls of hurricane force near the centre at sea.

These facts will enable the character of the winds in the west quadrant of the cyclonic storms of the rains proper to be understood. Before they commence to form, and whilst they are forming, the regular southerly winds of the season are to a large extent suspended in Bengal and at the head of the Bay. Light unsteady winds prevail, and the weather is sultry and oppressive. A rush of strong monsoon winds commences in the centre of the Bay, drawn or pressed forward by some force. Squalls begin to occur and increase in frequency and intensity, and a small whirl (perhaps) begins to form. If this be the case, the whirl thus started, after some time varying very considerably in length according to circumstances, advances landwards and carries heavy rain with it to the districts over which it passes.

It is hence the winds in the southern and eastern quadrants which bring up the energy that starts and maintains the storm. They are, moreover, the normal winds of the season, intensified locally by the cyclonic indraught. The winds in the western quadrant are abnormal winds, with little or no energy, dragged into the storm.

The following descriptions of the winds at the head of the Bay just before these storms, as experienced by vessels, are extracted from their logs:—

Ship.	Time.	Distance and bearing of centre of cyclonic storm.	Remarks.
S. S. *Argo* . . .	13th June 1886.	Storm forming 130 miles E. N. E.	Winds light and flying all round the compass.
Foyle	13th June 1886.	Storm forming 80 miles S. E.	Baffling winds in all directions with calm intervals.
Duke of Edinburgh .	14th June 1886.	130 miles E. .	Variable winds from all quarters.
Star of Albion . .	26th June 1883.	230 miles E.N.E.	Light northerly winds, but very unsteady in force and direction.
St. Magnus . . .	26th June 1883.	160 miles E. by N.	*Morning.*—Faint airs and calms. *Afternoon.*—Almost calm; wind at times, but variable, gusty; rain in torrents.
Janet Cowan. . .	18th July 1882.	35 miles E. by S.	Wind very unsteady, shifting all round the compass.
Mira	18th July 1882.	100 miles N. E..	Light N. E. winds of force 2.
S. S. *Herat* . . .	6th Sep. 1882.	200 miles N. E..	Light N. E. winds. Weather generally fine, with rain; clouds about, but much light misty, drizzling rain; clouds forming and then disappearing altogether before reaching the ship. Heavy bank to south-east.
P. V. *Coleroon* . .	24th May 1887.	220 miles S. E..	Light variable winds and calms during the morning.
P. V. *Sarsuti* . .	20th Aug. 1888.	Storm forming about 50 miles S. E.	During the early part of the day the atmosphere was quite calm and from 10 A.M. to midnight wind was very light (force 1-2).
S. S. *City of Cambridge* .	21st May 1893.	Storm in course of formation about 120 miles S. S. W.	Variable airs and calms.

Ship.	Time.	Distance and bearing of centre of cyclonic storm.	Remarks.
S. *Ardencraig* . .	9th Sep. 1893 .	130 miles S. S. E. by E.	Light northerly airs of force 1.
F. L. V. *Torch* . .	8th July 1894 .	Storm forming about 110 miles S. W.	Light breezes and fine throughout the day.
S. S. *Nevasa* . . .	16th Sep. 1895 .	120 miles S.S. E.	*Morning.*—Light variable winds of force 2.

These cases, selected from a large number, illustrate the character of the winds in the north-west angle of the Bay before and during the approach of a small cyclonic storm of the rains proper. The winds shift round to the north-east and form a part of the cyclonic circulation which is being established. They are, however, generally very light and unsteady, and are of little or no importance so far as the maintenance of the cyclonic circulation is concerned. They, moreover, stand in the most marked contrast to the winds which prevail in the opposite quadrant. Sailors should recognize fully that light and unsteady north-easterly airs, such as described above, in the north-west angle of the Bay during the monsoon months of June, July, and August, and the first half of September are an almost certain indication that a cyclonic storm is forming or is in existence in the north of the Bay.

Character of winds to the north and west of cyclonic storms of the Transition periods.—The circumstances are different during the formation of storms in the May and October Transition periods. During these two periods the south-west monsoon is not in full possession of the Bay. In the first or May transition period the south-west monsoon has not advanced up the Bay, and hot-weather conditions prevail in Bengal and at the head of the Bay. In the latter, or October transition period, it is retreating down the Bay and the (so-called) north-east monsoon is setting in on the Coromandel coast. The character of the winds in these two cases differs slightly at the head of the Bay immediately before the advent of a cyclone. It may be premised that these cyclones are occasionally very extensive and fierce storms. In the inner central or storm area the winds are governed by the cyclone only, and show that rotatory motion, combined with indraught to the centre, which is the essential feature of rapid cyclonic air motion. The winds are, however, in all cases influenced more or less to a very considerable distance away from the inner storm area. If the cyclonic storm be at a considerable distance from the place of observation and the wind that is slightly influenced by its action or indraught be the normal wind of the season, its only effect may be to strengthen that wind, which will hence be apparently normal in character, but steadier and stronger than usual. Hence it may happen that a wind from such a direction, which is

usually a fair weather wind, may under these conditions blow directly into a cyclonic storm. This is especially the case in the cyclones of the months of October and November at the head of the Bay.

The winds that then prevail at the head of the Bay are from north with more or less easting. The following tables give the mean wind directions at the more important ports on the coast of the north of the Bay for all the months April to December:—

Mean Wind Direction.

	Akyab.	Chittagong.	Saugor Island.	False Point.	Gopalpur.	Vizagapatam.
April . . .	S. 6° W.	S. 9° W.	S. 14° W.	S. 31° W.	S. 7° W.	S. 45° W.
May	S. 24° W.	S. 1° E.	S. 8° W.	S. 23° W.	S. 1° W.	S. 40° W.
June . . .	S. 3° E.	S. 24° E.	S. 12° W.	S. 37° W.	S. 12° W.	S. 56° W.
July . . .	S. 1° E.	S. 30° E.	S. 21° W.	S. 53° W.	S. 17° W.	S. 71° W.
August . . .	S. 1° E.	S. 25° E.	S. 13° W.	S. 47° W.	S. 12° W.	S. 70° W.
September . . .	S. 8° E.	S. 22° E.	S. 2° W.	S. 20° W.	S. 6° W.	S. 61° W.
October . . .	S. 64° E.	N. 11° W.	N. 8° W	N. 50° E.	N. 45° E.	S. 73° E.
November . . .	N. 3° E.	N. 19° W.	N. 3° E.	N. 27° E.	N. 32° E.	N. 58° E.
December . . .	N. 8° W.	N. 24° W.	N. 3° E.	N. 32° E.	N. 43° E.	N. 64° E.

The following table gives the directions in the preceding table to the nearest points of the compass for the information of sailors:—

	Akyab.	Chittagong.	Saugor Island.	False Point.	Gopalpur.	Vizagapatam.
April . . .	W. S. W.	S. by W.	S. by W.	S. W. by S.	S. by W.	S. W.
May	S. S. W.	S.	S. by W.	S. S. W.	S.	S. W.
June	S.	S. S. E.	S. by W.	S. W. by S.	S. by W.	S.W. by W.
July	S.	S. E. by S.	S. S. W.	S.W. by W.	S. S. W.	W. S. W.
August . . .	S.	S. S. E.	S. by W.	S. W.	S. by W.	W. S. W.
September . . .	S. by E.	S. S. E.	S.	S. S. W.	S. by W.	S.W. by W.
October . . .	E. S. E.	N. by W.	N. by W.	N. E.	N. E.	E. S. E.
November . . .	N.	N. N. W.	N.	N. N. E	N.E. by N.	N. E. by E.
December . . .	N. by W.	N. N. W.	N.	N.E. by N.	N. E.	E. N. E.

The preceding tables require for exact information to be supplemented by another showing the amount of shift which takes place in the wind direction during the day. This can only be given for Chittagong, Saugor Island, and Rangoon, at which there are continuous wind-registering instruments.

It will be sufficient to give it for the month of October only, in connection with the present subject—

Mean wind direction at various hours during the day in month of October.

Station.	Mean Wind Direction.					
	4 A.M.	8 A.M.	Noon.	4 P.M.	8 P.M.	Midnight.
Chittagong . .	N. 36° E.	N. 55° E.	N.	N. 86° W.	S. 75° W.	N. 18° E.
Saugor Island . .	N. 11° W.	N. 1° E.	N. 55° W.	N. 47° W.	N. 56° E.	S. 37° E.
Rangoon . . .	S. 35° E.	S. 44° E.	S. 56° E.	S. 2° E.	S. 6° W.	S. 17° W.
Calcutta S. G. Office .	N. 65° W.	N. 24° W.	N. 54° W.	N. 60° W.	N. 46° W.	S. 68° W

The first two tables show that at the mouth of the Hooghly and in the north-west angle of the Bay the mean or ordinary wind direction is between north and north-east in October and November. There is considerable shift in the direction of the wind during the day at the coast stations due to the heating of the land. How far this extends seawards, and to what extent the winds are modified in the open sea in the north of the Bay, can only be surmised at the present time, as the data for the discussion of the changes of wind during the day over the sea area are too limited to give reliable results. It is, however, almost certain that the winds in the north-west angle of the Bay shift through at least two or three points during the day, veering near the coast from east of north to west of north during the afternoon, and backing during the night and early morning from west of north to east of north.

The winds in November over the north of the Bay are similar in character, and are practically from the same direction as in October. They are, on the whole, slightly stronger and steadier. Hence the preceding remarks apply equally to the month of November, and also to the first-half of December.

The preceding remarks have described the normal steady winds of the months of October and November, which are emphatically the cyclone months in theBay. If a cyclonic whirl forms at that time in the Bay, it is usually generated in the centre of the Bay, and advances in some direction between north-east and west, the average direction being north-west. The tendency of such a whirl is to produce north east winds in the north-west quadrant, or in

the north-west of the Bay, and also to cause them to shift round to east if the cyclone takes a north-west or west track.

Hence the effect of the distant cyclone is generally (*i. e.*, in at least two cases out of three) to strengthen the north-east winds and to give them a tendency to veer to east, and also to increase their steadiness, and so long as the centre is at a considerable distance, the weather is fine and bright, and atmosphere frequently unusually clear. Hence it may be that when these winds are apparently most favourable for a ship outward bound from the Hooghly and the weather also even finer looking than usual, they are really feeding into a cyclonic storm further south.

They are in this case exceptionally treacherous and dangerous as they may carry a ship southwards in front of an advancing cyclone, where she would not have sufficient sea-room to be able to manœuvre and escape from the inner storm area.

It will thus be seen that north-east winds at the head of the Bay, and more especially in the north-west angle of the Bay, during the months of October and November, may indicate entirely different weather conditions. They may be—

1st.—Merely the normal winds of the season and accompany fine clear weather in the north of the Bay and in Bengal, and either fine weather or squally weather with rain in the south of the Bay, more especially in the neighbourhood of the Coromandel coast. In this case they are generally light, and shift through two or three points during the day in consequence of the heating of the land by day and its cooling by night.

2nd.—If these north-east winds are stronger and steadier than usual this may be due to one of the two following causes:—

(*a*) A stronger north-east monsoon than usual on the Coromandel coast and in Southern India. In this case weather is usually showery with much rain and strong winds in the Carnatic, and squally in the Bay of Bengal off the Coromandel coast. During such a period pressure is frequently unusually high in Northern India, and fine, clear weather with moderate west or north-west winds prevails in Bengal and the Gangetic Plain.

(*b*) The formation and existence of a cyclonic storm in the centre or south of the Bay. In this case the weather is generally unusually fine and the air remarkably clear.

The following are descriptions of the north-east winds which have prevailed at the head of the Bay, during the formation and northward movement of

five of the largest cyclonic storms of recent years in October and November :—

First example from the Calcutta Cyclone of 1864, which struck the Bengal coast near Contai on the 5th of October.

Ship.	Date.	Distance and bearing of centre.	Remarks.
Proserpine . . .	2nd October .	580 miles south-south-east.	*Morning.*—Fine clear weather with light winds and calms. *Afternoon.*—Wind east-north-east. Fine clear, weather. Light winds. *Midnight.*—Fine and clear.
	3rd " .	270 miles south.	*Morning.*—Wind north-east; fine and clear. *Noon.*—Weather began to change.

Second example from the Backergunge Cyclone of October 1876, which struck the mouth of the Megna on the night of the 31st October—1st of November.

Ship.	Date.	Distance and bearing of centre.	Remarks.
Tennyson. . . .	26th October .	Storm forming .	She was going up the centre of the Bay at this time. Previously, weather had been cloudy and showery, but on the 26th October she got into north-east winds and the weather cleared beautifully.
	27th " .	Ditto .	Fine steady north-east breeze, with clear weather all day.
	28th " .	358 miles south	Fine steady breeze from north-east to north-north-east all day.

Third example from the Midnapore Cyclone of October 1874, which struck the coast near Balasore.

Ship.	Date.	Distance and bearing of centre	Remarks.
Ireshope . . .	11th October .	Immediately before the formation of the storm.	*Morning.*—Calm and clear. 1 P.M.—Light variable airs and sultry. 8 P.M.—Wind north-north-east. *Midnight.*—Light winds and fine clear weather.
	12th " .	Ditto .	*Morning.*—Wind north-east; very light winds and clear weather. *Afternoon.*—Light winds from north-north east and very fine clear weather.

Fourth example from the False Point Cyclone of September 1885.

Ship.	Date.	Distance and bearing of centre.	Remarks.
P. V. Coleroon . .	20th September	450 miles south-south-east.	The weather was fine, sky unclouded, night remarkably clear. Light airs from north-east; vessels could be distinguished at a great distance.

Fifth and sixth examples from the Port Blair Cyclone of November 1891, which crossed the coast of the Sunderbuns to the east of Saugor Island on the morning of the 6th November.

Ship.	Date.	Distance and bearing of centre.	Remarks.
Arratoon Apcar . .	2nd November	About 600 miles south by east.	Noon to 4 P.M.—Weather fine with a moderate north-east wind and sea. 8 P.M.—Wind shifted to east-north-east but continued moderate in force. Weather cloudy.
Canara	5th November	200 miles south-west at 8 A.M. and 100 miles south-west at 4-20 P.M.	4 A.M.—Fresh easterly breeze and cloudy weather. 8 A.M.—Light E. N. E. breeze. Noon.—Moderate E. by N. breeze. 8 P.M.—Moderate to light E. N. E. breeze. Overcast.

Hence it should be carefully remembered that north-east winds in the north-west angle of the Bay are in October and November very treacherous winds, and if a captain about to leave the Hooghly and proceed southwards in either of these months sees that the wind is unusually steady from north-east and the weather remarkably fine and clear, he should consider that it may perhaps be due to, and be an indication of, a distant cyclone. He should also remember that if there be a cyclonic storm forming in the Bay, it may come up and overtake him when he is close to a lee shore. He should endeavour, therefore, to ascertain before running southwards (perhaps directly towards the centre of a fierce cyclone) from the Calcutta daily weather reports, whether any disturbance has commenced in the centre of the Bay; and if he decides to proceed on his voyage, to watch his barometer and the weather carefully, and if the weather become suspicious, endeavour to ascertain the bearing and line of march of the cyclone that has almost certainly formed, and take the earliest precautions to avoid, if possible, being caught up by it.

General character of barometric changes during storms in the Bay of Bengal.—The remarks on this subject in the preceding chapter (*vide* pages 59 to 67) have indicated that small barometric changes are the rule in the Bay of Bengal, and that large changes are, not only the exception, but are very rare indeed. They have also shown that the small changes which accompany stormy weather in the Bay take place usually at a slower rate than the regular motions. For a fall of two-tenths of an inch in 24 hours at a given place is of very occasional and rare occurrence, whilst the total fall and rise due to the diurnal tides on the average exceeds a tenth of an inch in each of the six-hourly intervals between maximum and minimum. Hence it is that they are so rarely obscured or obliterated by the changes due to cyclonic storms. Consequently, due allowance must be first made for these regular changes, if we wish to ascertain what the irregular changes are—which are the only part that we are concerned with in determining the probable weather. Hence also exactness and accuracy of observation are as essential in the Bay of Bengal as a good barometer.

There is a belief fostered by certain descriptions given in certain works on Physical Geography (probably exaggerated) of the steady large fall of the barometer for hours and days before storms, and of the long warning it thus affords to observant mariners of the approach of severe storms.

It is certainly not the case in the Bay of Bengal. In the smaller cyclones the barometer rarely falls more than two to three-tenths of an inch at any place over which a storm passes. In the larger cyclones the barometer falls very slightly in the outer storm area of squalls and strong winds. It is only in the inner storm area—that portion of the storm which sailors should use every effort to avoid, and in which the wind blows with hurricane force—that the barometer falls rapidly.

The curves given in Plate XLVI at the end of the book show far more plainly than words the character of the movement of the barometer during the passage of a large and violent cyclonic storm over a place in the Bay of Bengal or the adjacent Coast districts.

The first curve gives the barometric readings taken at hourly intervals at Calcutta during the great Calcutta cyclone of October 1864. The centre passed Calcutta at a distance of 20 to 30 miles to the west.

The second curve gives the readings taken on board the *Coleroon* during the Midnapore cyclone. She was about 20 miles to the west of the cyclone centre when nearest to it. The vessel was moving during the storm, and hence the curve does not represent the actual changes at a particular place such as would have occurred if the vessel had been stationary.

The third curve gives the readings taken at False Point Light-house (almost identical with the readings taken on board the British India Steamer the

Booldana, which was at anchor off False Point) during the cyclone of September 1885, the calm centre of which passed over False Point.

These all show the same thing, *viz.*, that the fall of the barometer is not only slow first of all, but also such as frequently occurs during slightly unsettled weather in the Bay or in India, and has no special features on the large scale, such as could have given any certain and reliable indication of the approach of a deep depression and of the violent hurricane winds which prevailed during each of these storms. It is only when that portion of the storm proper, which may be termed the inner storm area, reaches the observer or ship, that the barometer commences to fall with excessive rapidity. The False Point traces is exceedingly instructive from this point of view.

To sum up the preceding remarks, all experience shows that in the larger storms in the Bay the fall of the barometer in the outer storm area proceeds very slowly and is small in amount, and is only large in the inner storm area—that area which the mariner should use every effort to avoid. In other words, the barometer in the Bay of Bengal only falls rapidly when the mariner has entered the dangerous inner circle of hurricane winds of an intense cyclone, and is hence as ordinarily employed, not an indicator of approaching danger. This is, however, just what might be expected. The decrease of pressure, measured by the fall of the barometer, is not only caused mainly by the winds, but accompanies the violent winds and does not precede them.

The following extracts—a few out of a large number—from the logs of vessels, which include opinions of captains and pilots, will confirm these remarks:—

The commander of the *Kedgeree* pilot vessel, which was anchored at Kalpee during the Calcutta cyclone of 1864, says: "Our barometer gave no indication of anything extraordinary till the hurricane was on us, when it fell with unexampled rapidity."

Mr. W. R. Williams, pilot, writing of the Midnapore cyclone, says that "at 1 P.M. of the 15th, only a few hours before the storm passed, we had every appearance of a cyclone *except a low barometer*."

Mr. Clarke, Magistrate of Chandbali, writing of the same storm, says:—"I think the heavy wind from the east, the *high* barometer and the cross swell, ought to have warned the captain and pilot of the *Sir John Lawrence* of the cyclone that was approaching."

Mr. Wilson, speaking of the storm, says:—"The shortness of the warning given by the barometer has been noticed and is illustrated by the entries of the barometric observations taken on board the *Coleroon*. The fact that two vessels were caught in the vortex while endeavouring to get to sea also points to the suddenness with which the storm burst over the Sandheads. The commanders of the pilot brigs, well acquainted with all the phenomena

of the cyclones of the region, and perfectly familiar from long experience with all the indications of their approach, generally manage to keep their vessels at least at a safe distance from the centre of any storm which may be travelling up the Bay. It is a point of honour, however, as well as a necessary rule, to hold on to the station as long as it may appear safe to do so : as when the brigs run down to the southward it may take them some days to get back, and great inconvenience and delay may thereby be caused to vessels either outward or inward bound. In the present case the commanders of the brigs seem to have misjudged the distance of the storm, *probably misled by the slowness of the fall of the barometer before they were actually within the area of hurricane winds.*"

The following extract is from the log of the ship *Thessalus*, which passed through the Backergunge cyclone :—

"*Tuesday, October 31st, 4 A.M.*—There was no indication by the barometer of more than a gale or stiff breeze, but at 8 A. M., when it was too late to do anything, the gale being on us, the barometer fell considerably."

The following is an extract from a report of the weather at False Point, by the light-house keeper during the cyclone of October 10th to 16th, 1882 :—

"*Friday, 13th, 6 A. M.*—The weather having a very threatening appearance and the squalls blowing rather heavy, I commenced taking two-hourly observations of the barometer, but as yet that instrument showed no indication of bad weather."

It is not necessary to give further extracts from logs, as the preceding illustrate sufficiently this feature of cyclonic storms and cyclones in the Bay of Bengal.

Banks of clouds.—When a cyclonic storm has formed, large masses of air are carried rapidly upwards in the body of the cyclone or over a considerable portion of the inner storm area. The aqueous vapour with which it is laden is in part condensed rapidly. Huge nimbus, pallium or rain clouds are formed from which rain is poured down in torrents. Hence, over the central area there is a permanent dense black mass of clouds which move with, and is a part of, the cyclone. This permanent state is, of course, one of appearance or passage only. The air, as it rises up and passes through the cloud-charged space, has a portion of its aqueous vapour condensed, and thus contributes or adds to the mass of the cloud, whilst at the same time the cloud is continually losing a portion of its mass by the rainfall. The cloud-mass is hence in a state of constant growth and decay. Its appearance at a distance is that of a huge bank of clouds resting on the horizon, which retains its form unchanged for hours. It is usually most conspicuous about sunrise and sunset. If a ship should travel at about the same rate as the cyclone, this huge

bank of clouds may be observed for several days in succession. As also much electric action goes on in the body of a cyclone, due probably to the intermixture of masses of air in different states of humidity, temperature, &c., or perhaps—which appears to be more probable—to the friction of the small globules or vesicles of the condensed aqueous vapour in the earlier stages of their formation against the rapidly upward-moving air, much violent electric action goes on, more especially in these quadrants (*viz.*, the eastern and northern), where the air is chiefly being carried upwards. At night the lightning is visible at immense distances. If, as is frequently the case, it may be seen by reflection from higher clouds, calculation indicates that the reflection of the lightning might be seen in this way at distances of from 300 to 400 miles under very favourable circumstances, and at distances of 50 to 100 miles under ordinary circumstances, such as are likely to occur in any storm. Hence, the appearance of a dense bank of clouds on the horizon which retains its shape for hours practically unchanged, and in which (especially at night) frequent electric action or lightning is seen, is an almost certain indication of a distant cyclonic storm. The indication is even more valuable if the same appearance be observed on two or three nights in succession. It is therefore an indication of considerable importance, and is frequently the first marked sign of the distant formation and approach of a cyclonic storm.

The following are a few examples extracted from the meteorological information contained in the logs which have been sent in to the India or Bengal Meteorological Office.

Captain Smart, in command of the pilot vessel *Chinsurah* at the Sandheads during the great Calcutta cyclone of 8th October 1864, thus describes the bank of clouds in his private note-book :—

" During the day, patches of clouds of a very deep blue, like indigo, overhead and to the eastward; 6 P. M. a very heavy bank of clouds to north-west, of a deep maroon colour. First part of night inclined to be squally from east to south-east. Before I went to bed I observed very suspicious, sharp, and low forked lightning to the south-east."

The ship *Lightning* passed over the centre of the Bay just before the formation of the Backergunge cyclone and advanced to the head of the Bay 150 or 200 miles in front of the cyclone, and was overtaken by it on the 31st, as she was unable to obtain a pilot to enter the Hooghly on the 28th. When in Lat. 18° 39′ N., the Captain writes in his log :—" There has been since the 23rd a disagreeable-looking cumulus (indicative of a storm) in the south-east quarter every evening, with much lightning." On the 29th, when in Lat. 19 38′ N., Long. 89° 18′ E., he says, "There is still that disagreeable nimbus in the south-east quarter, with lightning going across our stern."

Several other vessels, describing this storm, speak of "the heavy bank of clouds" which they observed when they were in comparatively fine weather and at considerable distances from the storm centre.

Again, the ship *Patrie* advanced up the head of the Bay just before the Midnapore cyclone, much in the same way as the *Lightning* in the previous case. Her log of the 12th October, when she was in Lat. 17° 58′ N. and Long. 88° 54′ E., states, "Sky very black to the south-west, with frequent lightning;" and again on 13th October, when in Lat. 19° 27′ N., Long. 88° 34′ E.: "Sky very black to south-east at sunrise."

The following description of the appearance of the distant cloud-features of the False Point cyclone as seen by Mr. S. R. Elson, pilot, from the pilot brig at the Sandheads is both accurate and interesting:—

"All this day, say from 9 A.M. to 2 P.M., the sky was comparatively clear of cloud, the surface breeze and low driving scuds being confined to a very thin stratum. Now and then smoke-like scuds would stretch up from the surface right across the wind direction, as I have observed in most cyclonic storms, more especially in the small whirls of the rainy season; the current immediately above the surface coming from about four points to the right of the wind direction. But, most remarkable, there seemed to be perfect stillness of the air strata at a small height above the hurricane wind, so far as any lateral direction was concerned, for tall tufts, or 'thunder heads,' as they have been termed, rose here and there, straight up towards the lofty cirro-cumulus, having level vapour planes to each, undisturbed by the indraught surface winds of the storm. These thunder heads, or tufts, were mostly to the south-east; we had but very little rain after 9 A.M., when the wind had gone to the southward of south-east."

The following are a few of the brief descriptions extracted from recent meteorological logs:—

"There was a dark heavy bank of clouds to east and south-east; otherwise, sky was clear over head, and to the north and west."

"The sky was one mass of heavy black clouds and rain, like a black wall to west-north-west."

"There was a heavy bank of clouds to the west-north-west. Weather assuming a very threatening appearance, with heavy wild-looking clouds to the north and north-west."

"Low cloud in the eastern horizon, with lightning occasionally."

"Clear sky overhead, but round the horizon to east, all dark; weather sultry, with heavy banks of clouds on the horizon."

The following statement gives the more important data in a tabular form,

showing more especially the distance at which the cloud-bank has been observed in a few cases :—

Ship.	Cyclone.	Distance and bearing of centre.	Description of cloud-bank.	Weather at time of observation of cloud-bank.
Chinsurah .	Calcutta, 2nd to 5th October 1864.	375 miles S. S. E.	6th October.—Heavy bank of clouds to south-east.	Fine weather.
City of Venice .	Backergunge, 27th October to 1stNovember 1876.	400 miles E. N. E.	27th October.—Heavy bank on north-east horizon.	Moderate breeze, calms and light winds.
Lightning .	Ditto . .	560 miles to S. W.	29th October.—Disagreeable-looking thunder cloud in south-east with much lightning.	Variable winds, cloudy.
Japan . .	Ditto . .	400 miles E. N. E.	29th October.—Heavy bank of clouds to north.	Every appearance of a gale.
Allahabad .	Ditto . .	350 miles S. W.	29th October.—Heavy bank of clouds to south, blue color, and very dark.	Strong south-east wind, constant rain and heavy squalls.
P. V. Foam .	Ditto . .	350 miles S.	30th October.—Bank of clouds to south-east and lightning.	Calms and slight sea.
P. V. Coleroon	Ditto . .	Ditto . .	Ditto . . .	Ditto.
Patrie . .	Midnapore, 13th to 16th October 1874.	115 miles S. E.	12th October, 5 A.M. to 8 P.M.—Sky very black to south-west and frequent lightning.	Winds north-north-east, variable and north-east.
P. V. Coleroon Patrie.	Midnapore, 13th to 16th October 1874.	200 miles, S. S. E.	13th October, day-break.—Sky very dark to south-east.	Weather cloudy, and frequent lightning at different portions of horizon.
Duke of Devonshire.	Storm of 12th to 18th October 1882.	150 miles, S. S. E.	Morning, 13th October. — Heavy bank of blue-black clouds on eastern horizon.	Heavy squalls and gale increasing ; much lightning and rain.
P. V. Cassandra.	Storm of 14th to 22nd June 1886.	160 miles, S. by E.	14th June, 8 P.M.—Dark heavy bank of clouds to east and south-east with rising sea.	Weather clear overhead and to north and west, and gloomy to east.
British Provinces.	Storm of 25th June to 4th July 1883.	60 miles E. N. E.	27th June.—Heavy bank of clouds to north-west.	Distant thunder, lightning, and rain.
Iolanthe . .	Storm of 13th to 17th May 1884.	300 miles E. S. E.	16th May.— Sky hazy, and bad-looking to south-east.	Light winds and calm, sea very heavy.

The preceding table shows that the bank of clouds is, as might be expected, a far more prominent feature of the larger cyclones of the transition periods than of the smaller storms of the rains. It also shows that the bank of clouds may under favourable circumstances be seen when vessels are at distances of 400 and 500 miles from the storm centre, and when they have fine weather with light winds and a smooth sea. It is hence an occasional valuable indication of the existence of a cyclonic storm, more especially if it be observed in the months of May and of October and November, when skies are usually clear, except in a storm area, if one be in existence.

Sky appearances.—The air, for some time before and during cyclones, is charged with a very large amount of moisture, and is almost saturated through a considerable thickness or depth of air. The condensation of this moisture, of course, gives rise to the heavy rain that characterizes cyclonic storms. The sun's light passing through air mixed with a large quantity of aqueous vapour, is absorbed to a considerable extent. The absorption is not the same for different colours or constituent portions of the whole sunlight, but is much greater for the green and blue than for the red.

In order to explain this action somewhat more fully, it is necessary to remind the reader that ordinary sunlight is not light of a single colour. If it were elementary and non-decomposable, it would admit of only increase and decrease in amount, such as in fact occurs every day as the sun rises and sinks in the heavens. It is really compounded of lights of a great variety of colours, each existing separately, but the whole producing a single effect upon the eye, and giving rise to the impression of a single colour. By passing a narrow beam of the sun's light through a prism, the colours are separated and placed side by side. The same is effected naturally in the rainbow, the rain-drops in this case playing the same part as the prism in separating the different coloured lights and arranging them in a fixed order side by side.

It has also been found out by simple experiments that when light enters a body through which it can pass, a smaller amount of light always passes out of the transparent substance than what enters it. A certain portion of the light disappears during its passage through the body, or is, to use the proper term, absorbed. It is also found that transparent substances differ very greatly from one another in the way in which they absorb light. Some, for example, absorb all the different coloured lights of which white light is composed, except that of one colour and hence the light which passes through is of that colour only. Other substances absorb the same proportion of each of the different coloured lights, and hence the light that issues is of the same compound or resultant colour as it was before entry, but it is diminished in intensity. This is, of course, what happens when sunlight passes through a moderate thickness of good glass or of pure water or air. There are, again, other substances which absorb the different coloured elements of white light in different propor-

tions, so that the light which issues from such a body is mixed together in different proportions to that which constitute ordinary white light, and is hence of a different colour depending upon the mixture. One substance which has this power of absorbing light of different colours in different amounts is damp air, or air containing a large amount of invisible aqueous vapour in suspension.

The sun's light is made up of violet, indigo, blue, green, orange, yellow, and red light, and of these damp air absorbs the blue and green much more largely than yellow or red. Hence, the light which comes through a great thickness of damp air contains a much smaller proportion of these colours (violet, blue and green), or what is the same thing a much larger proportion of the red and yellow rays than ordinary white sunlight, and hence appears to be a reddish colour, the depth of the tint depending partly on the thickness of the damp atmosphere passed through, which is of course greatest just before sun-set and after sun-rise, and also upon the amount of aqueous vapour in the air.

There are other effects due to the presence of very small particles of dust, crystals of ice, etc., in the air, which are more difficult to explain, but these hardly concern us in this section. The colours seen in the western horizon, at and after sun-set, the irridescent colours of very thin clouds occasionally seen in India, especially near the sea, coronas, halos, etc., are due to the action of these particles in sifting light. The mariner is referred to ordinary works on meteorology for explanation on these points.

In consequence of the actions explained above, the absorption of light by the damp mass of air in the body of a cyclone occasionally gives rise to remarkable colours in the sky, the most common effect being to give a reddish colouration varying from lightish red to darkish red to the clouds.

The following are a few examples of the very dark red tint that occurs under favourable circumstances before and during cyclone generation in the Bay.

Captain Keiner, the commander of the *Patrie* which passed through the area in which the Midnapore cyclone was formed 48 hours afterwards, thus describes the weather and sky appearances :—

"The weather is uncertain. Winds variable from north-west to east, and squally. The sea very tranquil, but the sun blood-red on the horizon when setting. Clouds of different sizes detached one from the other passing with great velocity."

The appearance of the sky is described in the following terms in the logs of the ships *Allahabad* and *British Sceptre* which passed up the centre of the Bay just before the Backergunge cyclone was formed, and were overtaken by it near the head of the Bay.

"*29th October.*—When the sun rose all the clouds were of a brick-dust appearance."

"*30th October.*—Very threatening appearance ; moon showing with a reddish glare, tinging banks of clouds with same colour."

The following are extracts from logs giving descriptions in the case of other cyclones:—

"The weather looks fine and more settled. At sun-set this evening the sky became awfully grand, a light appeared very suddenly in the east-north-east. It broke out like a large patch of red clouds, and then opened all over the heavens, making water, ship, and everything on board appear red."

"The stars had a sickly appearance, and the sun rose blood-red."

"A peculiar red glare in the sky all round the compass, especially to north and west."

"The sky assumed a most strange appearance. Orange coloured and pink clouds, and a red haze about the sun. All day floods of rain."

"The sky of dark red appearance to westward and eastward."

"A very red appearance all round horizon."

"The appearance at sun-set was very threatening, the sky being a bright scarlet all over."

"Dull heavy sky, with bright pink colour at sun-set."

"Sun-set sky very red-looking."

"Thick yellow haze giving a peculiar glare to the light."

This indication is, in the case of the smaller cyclones in the Bay during the rainy weather months, of little value, as reddish skies at sun-rise and sun-set will probably often be seen under the ordinary conditions of that period. They are however, much rarer in the months of October and November, when the atmosphere, especially in the north and centre of the Bay, is in its ordinary state not charged with large amounts of aqueous vapour (as it usually is in the rains). At such seasons (when the most dangerous cyclones are formed), very dark red sun-sets and sun-rises indicate that the atmosphere over a portion of the Bay is almost saturated with aqueous vapour, a state of the atmosphere such as is always highly favourable to, and precedes or accompanies cyclones. It is very valuable as an indication, as it evidently occurs either in the preliminary stages of cyclone formation, or is only visible at a considerable distance from the body of the cyclone or on the verge of the outer storm area. Hence its value as an indication when it is observed.

Occurrence of squalls before and during cyclonic storms.—It should be kept carefully in view by mariners in the Bay of Bengal that the formation of a cyclonic storm is a gradual process, and that it is only when the disturbance has passed beyond the initial stages that it becomes a storm in the proper sense of the word. The formation of a large storm is due to the prolonged continuance of actions, processes and changes of the same kind as those that are occurring in the atmosphere at all times when rain is falling and strongish humid winds are blowing. Whatever the causes and origin of cyclones may be, the history of all cyclones in the Bay shows that they are invariably preceded for longer or shorter periods by unsettled squally weather, and that during this period the air over a considerable portion of the Bay is gradually given a rapid

rotatory motion about a definite centre. During the preliminary period of change from slightly unsettled and threatening weather to the formation of a storm more or less dangerous to shipping, one of the most important and striking points is the increase in the number and strength of the squalls which are an invariable feature in cyclonic storms from the very earliest stages. First of all, the squalls are comparatively light and are separated by longish intervals of fine weather and light variable or steady winds, according to the time of the year. They become more frequent and come down more fiercely and strongly with the gradual development of the storm. The area of unsettled and squally weather also extends in all directions, and usually most slowly to the north and west. If the unsettled weather advances beyond this stage (which it does not necessarily do) it is shown most clearly by the wind directions over the area of squalls. The winds always settle down into those which invariably occur over an area of barometric depression or cyclonic circulation, or, in other words, are changed into the cyclonic winds of indraught to a central area of low barometer and heavy rain. As soon as the wind directions indicate that a definite centre of wind convergence has been formed in the Bay, it is also found that the centre never remains in the same position for any considerable interval of time, but that it moves or advances in some direction between north-east and west with velocities which not only differ very considerably in different storms, but also at different stages of the same storm.

This preliminary period of unsettled squally weather may extend over several days, or may last only a few hours. It is of course impossible to determine exactly the hour at which the change from the antecedent disturbed squally weather to the cyclonic storm takes place.

Hence the chief feature of this antecedent period or first stage in the formation of cyclonic storms in the Bay of Bengal is squally weather. In those parts of the Bay where south-westerly or southerly winds are blowing, the winds are generally strong, varying in force from 3 to 6 or 7. These winds become the winds which prevail in the southern and eastern quadrants of the cyclone, if the squally weather developes into a cyclone. In another portion of the Bay during the formation of a cyclone (always to the north or west of the area of strong southerly winds) is an area of light and variable winds (sometimes shifting in a few hours all round the compass) or of calms. But whatever the direction or character of the wind in any portion of the Bay may be, if a cyclonic storm originates and forms over it, the occurrence of occasional rain-squalls is the first indication of the commencement of disturbed atmospheric conditions, or of the threatening weather which may under favourable conditions develop into a cyclonic storm. These squalls are at first of short duration and comparatively feeble, but if they increase rapidly in frequency and intensity, they are an almost certain indication of the commencement, or of the existence of a cyclonic storm, and they become more and more prominent and more frequent and severe during the birth and growth of the cyclonic storm. It should, how-

ever, be carefully noted that squalls more or less severe occur under several sets of conditions in the Bay, and it is hence desirable to discriminate between these. This is the more necessary in order that it may be fully realized that whilst *squally weather is a necessary antecedent in time to the commencement of a cyclonic storm, squally weather is not necessarily followed by a cyclonic storm.*

Squalls of brief duration, lasting from a few minutes to one or more hours, may pass over vessels navigating the Bay due to a variety of causes. They appear to occur chiefly under three different sets of circumstances, and hence may be divided into three different kinds described in the following paragraphs.

1st.—Squalls which usually originate in Bengal or Orissa near the sea coast during the hot weather months of March, April, and May.—They generally occur in the afternoon or evening after the day sea winds have been blowing across the sea coast for some hours. Many of them appear to begin over the hills in Orissa, West Bengal, and East Bengal. In all cases when they occur in South Bengal, clouds appear to gather in the north or north-west quarter, and gradually acquire the black, dense appearance and rounded mushroom-shape characteristic of thunder-clouds. The rapid and irregular motion of these clouds, the manner in which portions of the clouds appear to be torn off from the rest, the large electrical action shown by the almost continuous thunder and lightning which frequently accompanies them, and the occasional occurrence of hail, and other features all indicate very considerable atmospheric disturbance, which is, however, usually confined to a very small area. The disturbance apparently gathers force for some time, and then rushes down as if from a higher altitude, giving violent winds along its path, and is attended with much thunder and lightning, and frequently with heavy rain or hail. The wind veers considerably during the passage of these squalls. As they generally come down from the north-west quarter in Bengal they are usually termed nor'-westers. These squalls appear to be of comparatively brief existence and to die away even more rapidly than they are formed. If they pass from the land to sea, they are then comparatively feeble and disappear at a short distance from the sea coast. They are hence chiefly felt in the neighbourhood of the Bengal and Orissa coasts in the months of April and May. They are occasionally very violent in the River Hooghly and the mariner should hence be on his guard in these months, especially as the first rush of the winds which accompanies them is usually very sudden, and the force of the winds is sometimes very great, nearly as great as in the severest cyclones. In a nor'-wester which passed over Calcutta in May 1883, the velocity of the wind, as indicated by an anemometer on the roof of the Meteorological Office, exceeded 100 miles per hour in the severest gusts of the squalls. Carriages were overturned, trees blown down, and some of the ships in the river were damaged. One steamer at least was obliged to remain a day later in port in order to repair the damages caused by the storm.

An examination of the whole of the information contained in the logs of the vessels sent in to the Meteorological Office shows that they are by no means uncommon near the Sandheads and at the entrance of the river. They are, so far as can be judged from the information in the Meteorological Office, rarely felt to the south of Lat. 20° N., and then only in the immediate neighbourhood of the Arakan and Orissa and Madras coasts. At the Sandheads they occasionally come down very fiercely and raise a very rough and nasty sea. Hence it is always advisable that mariners proceeding down the Hooghly in the months of April and May, when they see a dense bank of clouds in the north-west quarter, such as is usually indicative of the probable approach of one of these squalls, should prepare for a severe squall. This, it has already been pointed out, is very advisable, because these squalls always come down very suddenly, and the first rush of these storms is sometimes exceedingly severe.

The following statement gives brief accounts of some of these squalls contained in the logs of vessels sent in to the Meteorological Office during recent years, and will assist in illustrating the character and usual time of occurrence of these storms. In Plate XIX are shown the positions in which these storms have been met with by vessels during the past 20 years.

No.	Ship.	Date.	Position.	Character of squall.
1	*Kerbela* . . .	17th April 1883, 8 P.M.	Gopalpur .	Wind strong from north-west, (Force 7) squally, with thunder, lightning, and rain.
2	*Chilka* . . .	17th April 1883.	Ditto . .	Strong squall from north-west working round to south, with heavy rain, thunder and lightning. (Force of wind 7.)
3	Diary of Mr. S. R. Elson.	27th " " 10 to 11-30 P.M.	Saugor . .	The first cold blast of a north-east squall struck us. Wind in gusts from force 5 to 7. The wind kept persistently in the north-east till 11-30 P.M. when the rain ceased.
4	Ditto . . .	29th April 1883, 8 to 10 P.M.	Sandheads .	Was struck by the first blast of a well formed and wildish-looking arch of a nor'-wester from due north, with rain and lightning. It lasted for 2 or 3 hours, the wind hauling to north-north-west after it had blown for some time.
5	*Maharatta* . .	21st May 1883 .	Chittagong River.	Heavy squall from the north-west for two hours.
6	*Star of Denmark* .	24th " " 7 to 8 P.M.	Lat. 20°N., Long. 87°E.	North-west squall which lasted one hour.

No.	SHIP.	Date.	Position.	Character of squall.
7	*Coconada* . .	18th April 1884, 8 P.M.	Chittagong River.	Squall, with heavy rain and heavy gusts of wind.
8	*Booldana* . .	23rd April 1884.	Off Puri . .	Very heavy south-south-west squall.
9	*Ellora* . . .	21st „ „ .	Off coast between Coconada and Madras.	The weather was squally, with much lightning to the north and west and occasional violent squalls
10	S. S. *Australia* .	1st May „ .	Proceeding up River Hooghly.	Had heavy south-west squall, with vivid lightning and heavy rain, at 4 P.M.
11	S. S. *Pemba* . .	4th „ 1885	Lat. $19\frac{3}{4}$°N., Long. $89\frac{1}{2}$°E.	Heavy squall of wind, with incessant and very vivid lightning and heavy rain.
12	S. S. *Tenasserim* .	4th „ 1886.	Lat. 16°N., Long. 94°E.	Heavy squall of wind and rain from north-west, and vivid lightning from south-west and to north during the squall.
13	Ditto . . .	5th „ „ .	Lat. 19°N., Long. $90\frac{3}{4}$°E.	Heavy squall of wind and rain from the north-west, which lasted 40 minutes.
14	S. S. *Rossshire* .	13th „ „ .	Lat $19\frac{1}{2}$°N., Long. $87\frac{1}{2}$°E.	Heavy squall of wind and rain, accompanied with thunder and lightning.
15	Diary of Mr. S. R. Elson.	1st „ 1883, Evening.	At anchor at Diamond Harbour.	A very hard blast struck the vessel, due to an arched squall from west to west-south-west. It blew very violently until the rain began. The ship *Blair Athol*, which was half-mile lower down the river, was blown clean around.
16	Long Sand . .	8th March 1894, 10 A.M.	Sandheads .	Hard squall from north-west.
17	S. S. *Chindwara* .	17th April 1894, 11-30 A.M.	Lat. 20° 0'N., Long. 86° 32'E.	Fierce squall from west veering to west-north-west with heavy rain and vivid lightning.
18	S. S. *Oron* . .	17th April 1894, 5-40 P.M.	Lat. 19° 22'N., Long. 87° 46'E.	Heavy nor'-wester with rain.
19	S. S. *Huzara* . .	18th April 1894, 10 A.M.	Lat. 19° 22'N., Long. 86° 58'E.	Heavy squall from north-west.
20	S. S. *Ethiopia*. .	9th May 1894, 7-20 P.M.	Saugor . .	Ditto Ditto.
21	F. L. V. Eastern Channel.	13th April 1895, 8-30 A.M.	Eastern Channel.	Hard squall from north-west with heavy rain, thunder, and lightning.

No.	SHIP.	Date.	Position.	Character of squall.
22	S. S. *Nadir* . .	14th April 1895, 4 A.M.	Lat. 19° 26′N., Long. 86° 2′E.	Heavy north-west squall with light rain.
23	F. L. V. Eastern Channel.	7th May 1896, 8-30 P.M.	Eastern Channel	Heavy north-west squall with vivid lightning and thunder and heavy rain.
24	Ditto .	8th May 1896, 9-30 P.M.	Ditto .	Hard squall from north-west with heavy thunder and rain.
25	S. *Jura* . . .	20th May 1896, 10-30 P.M.	Lat. 20° 41′N., Long. 87° 29′E.	Heavy squall from north-west.
26	F. L. V. Eastern Channel.	20th May 1896, 11-30 P.M.	Eastern Channel	Very heavy squall from north-north-east with vivid lightning and thunder and very heavy rain.
27	Ditto .	27th May 1896, 8 P.M.	Ditto .	Hard squall from west-south-west with little rain and vivid lightning.
28	S. S. *Maharani* .	30th May 1896, 5 A.M.	Lat. 20° 0′N., Long. 91° 20′E.	Very heavy and thick nor'-wester.
29	F. L. V. Eastern Channel.	1st June 1896, 1-30 A.M.	Eastern Channel	Fierce squall with rain and thunder and lightning from south-west to north-west.
30	F. L. V. Mutlah .	3rd April 1897, 2 A.M.	Mutlah . .	Hard squall from west-north-west with force 10 and very little rain.
31	Ditto .	4th April 1897, 2 A.M.	Ditto .	Hard squall from north-west with much lightning, but no rain.

2nd.—Isolated squalls during the South-West monsoon.—Whenever a moist air-current is blowing, there is always a tendency to the formation and occurrence of rain-squalls. This tendency is apparently very much increased if the moist air-current meets with any sudden obstruction, or if it advances towards another air-current which differs much in temperature, humidity or other characteristic features. Hence, in front of the advancing south-west monsoon up the Bay in the months of May and June there are always frequent rain-squalls. These squalls appear to be very frequent in the neighbourhood of Ceylon just before the south-west monsoon current enters the Bay in May.

There is no doubt, notwithstanding the statements to the contrary made

by such authorities as Maury, etc., that what is ordinarily called the south-west monsoon in India commences at the entrance of the Bay and works up the Bay. It marches up the Bay in a more or less rapid rush at a rate of sometimes as much as 200 to 300 miles a day. Before it advances over the centre of the Bay during the latter part of May or beginning of June, light unsteady winds usually prevail; whilst near the head of the Bay local south-west winds blow across the coast into Bengal. These local sea-winds commence in February or March, and extend slightly seawards in April, and blow very strongly in April and May. They are, notwithstanding, mere local land and sea winds or breezes, and such as are always felt more or less off the shore of a country with a dry and heated interior. The first advance of monsoon winds over the south and centre of the Bay apparently resembles to some extent the sudden advance of a rapidly moving fluid mass into an inert mass, and there is much irregular and whirling motion. This shows itself by the frequent occurrence of squalls. During the prevalence of the south-west monsoon the winds blow intermittently, that is strongly for some days, and then fall off in strength. During these weak intervals the amount of rain in Northern India is comparatively small. These intervals of fine weather form what are called "breaks in the rains." During these breaks there is a tendency for the south-west monsoon to back down the head of the Bay. After some little time, and apparently under the increasing pressure of the winds in the south of the Bay, it advances again. Each advance is similar in character to the first great burst of the monsoon in May or June. It is a rush of strong winds over an area previously occupied by feeble winds, and is attended with more or less squally weather. Hence, squalls are of frequent occurrence over the Bay at the commencement of the monsoon, and over the north of the Bay during the whole monsoon period from May or June to October. As already pointed out, the air current which gives rise to these squalls is a damp humid currrent, bringing up vast quantities of aqueous vapour, and hence having a vast store of energy. If this energy be released and set free rapidly, the squally weather, which indicates slight atmospheric disturbance, may gather strength and grow into a large cyclonic storm.

The neighbourhood of the West Pegu and South Arakan Coast appear to be very liable to rain-squalls during the height of the monsoon. These are evidently due to the obstructive action of the Arakan hills, which are from 1,000 to 4,000 feet in height, and which divert the direction of the monsoon current from S.-W. to S. and S.-E.

The neighbourhood of the Madras Coast also appears to be subject to these squalls during the south-west monsoon months, July to September. The south-west monsoon winds which blow across the Bombay Coast are forced up across the Western Ghâts, during which they give up a considerable portion of their moisture, and thence proceed across the Deccan as comparatively dry winds. The wind directions of the Deccan stations indicate that the current

advances eastward across the Peninsula, and nearly at right angles to the current up the Bay of Bengal. Its velocity is considerable, nearly as great as that of the Bay of Bengal current. Much irregular motion and action occur near the meeting ground of these two aerial currents, just as is the case where two large rivers meet when, as is well known, there is much irregular and whirling motion, accompanied by up-rushes and down-rushes of small portions of the water. Hence, during the rains proper, rain-squalls are of occasional occurrence along and near the west coast of the Bay. This action is, as might be expected, most frequent near the head of the Bay. This interference of the Bombay branch of the monsoon current undoubtedly gives rise to frequent squalls in that part of the Bay, and it is probably in part due to this that small cyclonic storms occur so frequently during the months June to September.

The following table gives the more severe isolated squalls which have occurred in different parts of the Bay of Bengal during the south-west monsoons of the year 1883–98. It will be seen that the large majority of these occurred off the Ceylon, Arakan, and South Tenasserim Coasts and in the north-west of the Bay. Plate XX shows the distribution of isolated squalls of heavy to hurricane force, reported by vessels during the monsoons of the sixteen years 1883—98:—

Examples of isolated squalls in the Bay during the months June to September.

No.	Ship.	Date.	Position. Lat. N.		Position. Long. E.		Character of squall.	Reported force of wind in squalls.
			°	′	°	′		
1	*Tibre* . . .	20th July 1883 .	15	0	82	0	Violent squalls from west and north-west.	7
2	*Tibre* . . .	29th ,, ,, .	8	0	81	30	Very violent squalls from west and north-west.	7
3	*Westergate* . .	1st Sept. ,, .	14	0	84	0	Hard north-west squall, with thunder, lightning, and much rain.	6
4	*Tibre* . . .	18th ,, ,, .	6	0	80	0	Very violent squalls and continual rain from north-west and west-north-west.	7
5	*Thessalus* . .	30th ,, ,, .	6	0	87	0	Hard squalls from north-west.	4

No.	Ship.	Date.	Position.				Character of squall.	Reported force of wind in squalls.
			Lat. N.		Long. E.			
			°	'	°	'		
6	*Pelican* . .	18th June 1885.	Madras Harbour				Hard squall lasting about half-an-hour with heavy rain.	10
7	*Ganges* . .	22nd July 1886.	15	45	84	30	A violent squall from north-west, with thunder, lightning, and heavy rain.	8
8	*Governor* . .	29th June 1887.	12	0	84	0	Hard squalls from west-north-west to south-west.	6
9	*British Duke* .	8th July 1888 .	15	30	85	30	Very hard squalls from west-north-west.	6
10	*Euphrates* . .	14th Aug. „	Kyaukphu.				Very heavy squalls of wind and rain from north-west to north with much lightning and thunder.	5
11	S. S. *Maharani* .	12th July 1893 .	20	58	89	4	Hard squalls and heavy rain.	6
12	S. S. *Ellora* .	23rd „ „ .	6	15	80	30	Hard squalls.	6
13	S. S. *Peninsular* .	29th „ „ .	5	50	91	40	Hard squalls.	7
14	S. S. *Bancoora* .	3rd Aug. „ .	12	20	90	10	Violent squalls.	8
15	S. S. *Maharani* .	4th „ „ .	19	6	89	54	Tremendous squalls.	8
16	S. S. *Pentakota* .	4th „ „ .	19	24	90	1	Terrific squalls and heavy rain.	9
17	S. S. *Arratoon Apcar*.	30th „ „ .	7	26	98	44	Hard squalls and heavy rain.	7
18	S. S. *Rosetta* .	3rd June 1894 .	5	49	88	25	Occasional squalls and incessant rain.	6
19	S. S. *Lalpoora* .	3rd July „ .	9	45	82	0	Hard squall of wind and rain.	6
20	S. *Sheila* . .	6th „ „ .	7	46	81	5	Lightning, hard squalls, and heavy rain.	6
21	S. S. *Goa* . .	19th „ „ .	15	41	94	1	Hard squalls.	6
22	S. S. *Shahzada* .	21st „ „ .	16	40	93	0	Heavy gale, hard squalls and blinding rain.	8
23	S. S. *Purnea* .	12th Aug. „ .	17	0	95	45	Hard squalls.	5

No.	Ship.	Date.	Position. Lat. N.		Position. Long. E.		Character of squall.	Reported force of wind in squalls.
			°	′	°	′		
24	S. S. *Chupra* .	20th Aug. 1894.	8	30	97	50	Hard squall and heavy rain.	6
25	S. S. *Shahzada* .	3rd June 1895 .	19	0	92	38	Hard squall, thunder, and lightning.	6
26	S. S. *Rajpootana* .	4th July " .	8	45	81	10	Hard squalls and rain.	6
27	S. S. *Azamor* .	5th " " .	5	17	87	7	Hard squalls with rain.	6
28	S. S. *Pekin* .	14th " " .	5	59	91	26	Frequent hard squalls of wind and rain.	5
29	S. S. *Malda* .	1st Aug. " .	16	20	93	30	Hard rain squalls.	6
30	S. S. *Kt. of St. John.*	5th June 1896 .	4	59	85	21	Cloudy and hard squalls with rain.	6
31	S. S. *Sui Sang* .	1st July " .	9	3	97	14	Hard squalls with rain.	6
32	S. S. *Rohilla* .	12th June 1897 .	5	50	93	30	Frequent violent squalls of wind and rain.	7
33	S. S. *Rohilla* .	13th " " .	5	30	89	30	Frequent violent squalls of wind and rain.	6
34	S. S. *Peshawar* .	19th " " .	5	19	86	31	Hard squalls of wind and rain.	4
35	S. S. *Roma* .	27th " " .	17	45	91	40	Fierce squalls.	6
36	S. S. *Sui Sang* .	30th " " .	16	40	91	40	Hard squalls with rain.	6
37	S. S. *Clan Lindsay*	16th July " .	17	5	86	30	Very hard squalls and constant heavy rain.	7
38	S. S. *Haddon Hall*	16th " " .	16	7	85	26	Terrific squall and rain.	7
39	S. S. *Virawa* .	20th " " .	13	40	85	15	Frequent hard squalls with rain.	4
40	S. S. *Malta* .	2nd Aug. " .	20	1	87	54	Heavy rain and hard squalls of wind.	4
41	S. S. *Roma* .	2nd " " .	20	15	89	10	Fierce squalls at frequent intervals.	6
42	S. S. *Peshawar* .	8th July 1898 .	5	31	85	48	Passing hard squalls with rain.	6
43	S. S. *India* .	16th " " .	21	0	88	16	Frequent hard squalls and heavy rain.	6

The whole of the information up to the present date contained in the Meteorological Office records shows that isolated squalls during the south-west monsoon proper may occur in any part of the Bay, but chiefly in the following three portions of the Bay, arranged in order of frequency :—

1st.—The area between Lat. 12° N. and Lat. 16° N. and Long. 83° E. and Long. 94° E. (more especially in June and July).

2nd.—The neighbourhood of the Ceylon coast.

3rd.—The neighbourhood of the South Tenasserim and West Pegu coasts and the entrance to the Straits of Malacca.

Squalls during cyclonic storms.—These have already been fully described in page 139, and it is hence not necessary to repeat these remarks. Examples will be found in the history of the eight cyclones, Chapter IV.

An interesting point in connection with the occurrence of squalls in cyclonic storms and cyclones is their distribution with respect to the different quadrants of the storm. It is a point on which it is not easy to obtain very satisfactory information. An examination of the records in the Meteorological Office of the weather in the Bay of Bengal during the six years 1882-87 gives the data tabulated below.

The cyclonic area is divided into four quadrants, *viz.*, north-east, south-east, south-west and north-west, and the number of different occasions on which severe to intense squalls were observed in each of these quadrants during cyclonic storms or cyclones in the period 1882-87 is given in the columns of the following table :—

	NUMBER OF OCCASIONS ON WHICH SEVERE TO INTENSE SQUALLS WERE NOTED BY DIFFERENT VESSELS IN CYCLONIC STORMS.				
	N. E. Quadrant.	S. E. Quadrant.	S. W. Quadrant.	N. W. Quadrant.	TOTAL.
Months of May, June, July, August, and September	9	19	18	3	49
Months of October and November . .	18	13	12	14	57

The results are very interesting, and, although not pretending to exactness, probably give a rough approximation to the law of distribution. They show first that in the storms of the rains heavy squalls are far more frequent in the south-east and south-west quadrants than in the north-east and north-west quadrants, and that they are of rare occurrence in the north-west quadrant.

In the cyclones of October and November they occur with nearly the same frequency in all quadrants, but with a slight tendency to greater frequency in

the north-east than in the other three quadrants. The table also indicates that severe to hurricane squalls occur more frequently during the two-monthly period of October and November than during the five-monthly period extending from May to September.

The direction of the swell produced by cyclonic storms.—This important subject in connection with cyclones was first fully discussed by Colonel Reid, in Chapter III of his work "On the progress of the development of the laws of Storms and of Variable Winds" published in 1849. The explanation given in that chapter is, on the whole, adequate and satisfactory, and is adopted with some slight modifications in the following paragraphs.

The power of the wind blowing steadily for sometime over the surface of a sheet of water in producing ripples and waves is well known. When the winds are strong and approach in force to a gale, and blow over an extensive ocean-surface, waves of 30 to 40 feet in height, and separated by intervals of 200 to 500 feet are the not infrequent result. Measurements have been made by many observers which shew that these figures are fair estimates of such waves. It appears at first sight anomalous that the apparent effect of a strong and steady wind rubbing against the water-surface should be to give rise to these vast pulsations, oscillations or waves. The action of the wind is doubtless more or less irregular, and the waves are in part, if not entirely, due to the accumulated effect of these irregular actions, just as the sound of a violin string, produced by an apparently regular movement of the bow, is in reality due to a rapid succession of brief pulls and slips of the bow on the string.

Whatever explanation be adopted of the production of these large waves, there is no doubt of the general principle that air moving over a water-surface always produces waves, and that the magnitude of the waves is dependent upon the extent of water-area over which they blow and upon the force of the winds. There are several principles in connection with wave-movement which are deserving of notice in connection with the present subject.

As already stated, the rapid movement of air over the surface of the sea gives rise, by some species of cumulative action, to a continuous succession of large parallel waves so long as the winds are fairly steady in character. Waves that are produced in this manner travel steadily onwards in the same general direction so long as they meet with no obstruction, and if they pass beyond the area of strong winds, they decrease slowly in height and force. It occasionally happens that two or more sets of waves due to different actions and travelling in different directions over the same sea-area meet and, as it were, pass through each other. In this case the result in the meeting-ground is a confused motion usually described as a cross sea, and sometimes as a confused sea. This effect is developed to the greatest extent in and near the central or calm area of large cyclones, where the resultant action of the wave-motions transmitted in all directions is to give a peculiar up-and-down movement usually

described as a pyramidal sea, in which all appearance of onward wave-movement (which is one of the most striking properties of waves) has apparently disappeared. The following is a graphic description of such a sea extracted from the log of a vessel which went through the centre of a storm in the Bay of Bengal. "Wind north-east. Tremendous squalls, blowing with inconceivable fury; the sea rising in huge pyramids, yet having no velocity, but rising and falling like a boiling cauldron. I have never seen the like before. I was in the height of the terrible hurricane of September 1834 in the West Indies. I have been in a typhoon in the Chinese Sea, in gales off Cape Horn, and the Cape of Good Hope, but never saw such a confused and strange sea. I have seen much higher seas and heavier wind, but then the sea was regular and the wind steadier."

The effect of the squalls and other actions in cyclones in giving rise to a peculiarly heavy and confused sea is well described in the previous extract. The height or force of the sea due to a cyclonic storm in fact apparently bears no direct and simple relation to the general strength of the cyclone. For example, the Madras pier was breached in May 1881 during a storm of moderate severity, accompanied, however, by a peculiarly dangerous and violent sea. Again, Calcutta pilots described the sea they experienced in the False Point cyclone of September 1885, and the Balasore cyclone of May 1887, as exceedingly violent and dangerous, and almost appalling in appearance, even to men accustomed to the heavy seas of the south-west monsoon at the head of the Bay.

The waves, when originally produced by the action of the moving air on the surface of the sea, move at a rate which is mainly dependent upon the velocity of the wind, and are hence called forced waves, because their rate of motion is determined by the body or action which produces them, *viz.*, in this case the moving air. Waves, when produced by such an action, do not cease when the action stops, or when they pass in their motion beyond the sphere of action of the producing winds. In such cases they pass onwards in the same general direction as before, but gradually become smaller and smaller until at last they become imperceptible. In this case, as soon as they pass beyond the influence of the strong winds which produced them, they become what are termed free waves—waves which are propagated onwards in virtue of properties of the fluid itself and independent of any other cause. In this case the rate of motion depends upon the depth and other properties of the water. One observer many years ago measured waves up to 36 feet in height with crests 340 feet apart as a maximum and running up to 32 miles per hour. Theory seems to indicate that the swell in the outskirts of a cyclonic storm probably travels even more rapidly. If such waves meet with an obstacle, they tend to pass round it, and are more or less deflected according to circumstances.

In the case of cyclonic storms the winds blow from different directions in different quadrants. In the northern quadrants, in which easterly winds prevail, the air-motion will produce waves moving in a westerly direction. These

waves, when once fully produced, will tend to move in the same direction, and will not be dragged round the centre except perhaps to a very small extent, and will hence change their direction of motion as they pass onwards either not at all or very slightly. Such waves once produced will hence tend to pass away from the storm area, thrown off as it were like mud from a carriage wheel, and will continue to advance in the same general westerly direction for considerable distances over the open sea, gradually and slowly decaying; and if they meet a coast, will give rise to a heavy swell from the eastward, which will evidently increase in strength if the storm approaches that coast.

Similarly, waves or swell from the north-east will be transmitted by the action of the winds in the north-west quadrant.

The following diagram (Fig. 19) illustrates, according to Colonel Reid's explanation, the production of an easterly or east-south-easterly swell on the Madras Coast, and of a north-east swell at Trincomalee or on the north-east coast of Ceylon, in the case when a storm, which has formed near the Nicobars, is advancing westwards to the Madras Coast:—

Example of swell raised by a storm.

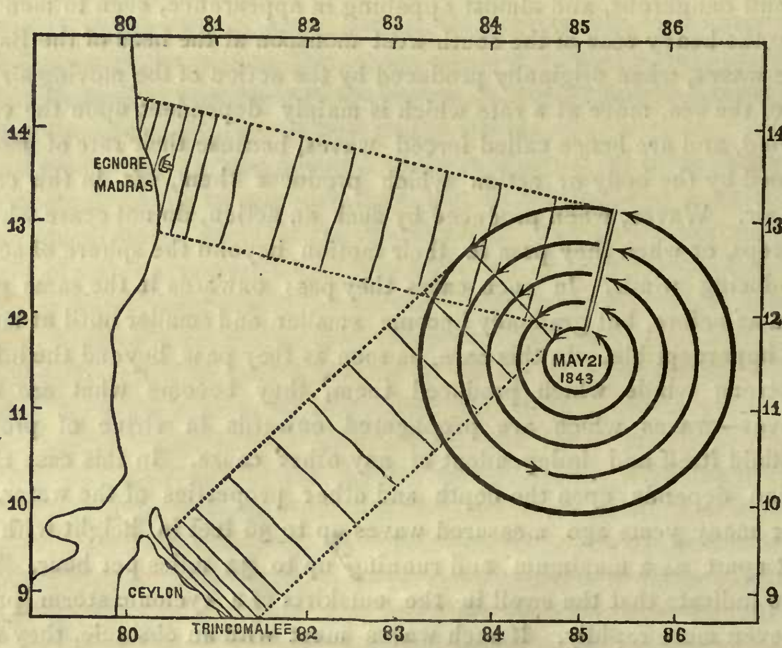


FIG. 19.

It is also evident from the preceding explanation that waves will tend to

pass out from each portion of a cyclonic storm, and give rise to swell passing out from the central storm area in all directions. The following diagram (Fig. 20) also, taken from Colonel Reid's book, illustrates this power of the winds of a cyclonic storm to give rise to swell passing outwards in all directions from the storm area :—

Cross sea and swell raised by a storm north of the Equator.

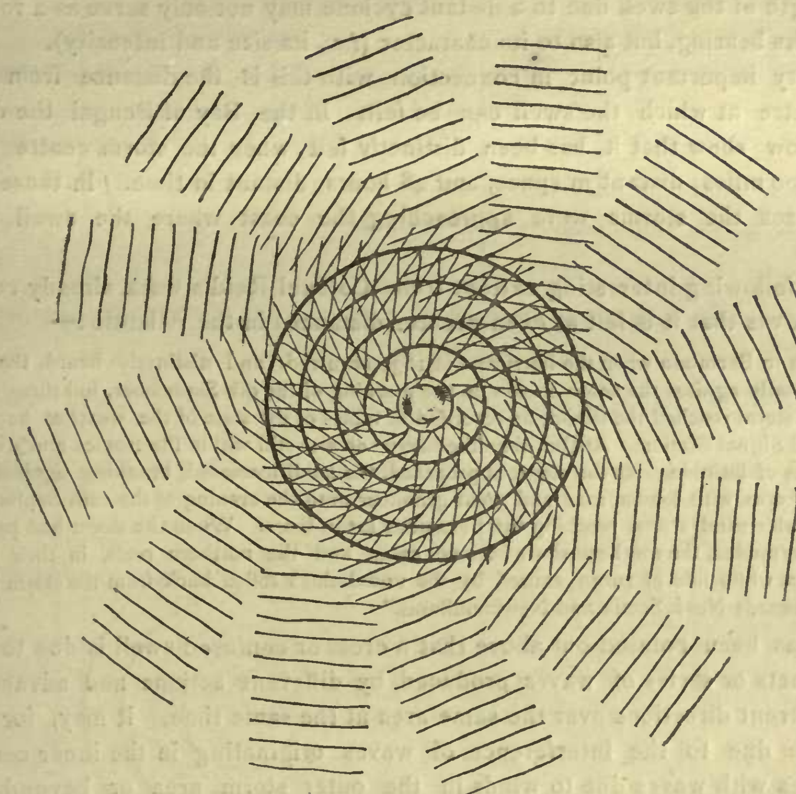


Fig. 20.

We have hence the following inferences from the previous discussions :—

1st.—If a cyclonic storm has formed in the Bay of Bengal, it is a kind of centre from which waves or swell tend to pass out in all directions, and the direction from which the swell is experienced on any part of the coast of the Bay outside the storm area nearly coincides with the direction or bearing of the storm centre. Numerous examples establishing or confirming this are given below.

2nd.—Again, it is evident that the strength of the swell or the distance at which it will be sensibly felt in the open sea, will depend partly upon the strength of the producing winds, and partly upon the distance over which the producing winds act with no considerable change of direction. The former, of course, depends upon the intensity of the winds and hence upon the intensity of the cyclone, and the latter almost entirely upon its extent. Thus the severe easterly winds of a small but intense cyclone may give rise to a heavy swell at the same distance from the centre as the moderate strong easterly winds of a much larger but shallower depression. Hence, with a certain amount of experience, the strength of the swell due to a distant cyclone may not only serve as a rough guide to its bearing, but also to its character (*i.e.*, its size and intensity).

A very important point in connection with this is the distance from the storm centre at which the swell can be felt. In the Bay of Bengal the data given below shew that it has been distinctly felt when the storm centre was at least 400 miles distant in space, and 48 hours distant in time. In these extreme cases the storms were approaching the coast where the swell was observed.

The following interesting extract from Colonel Reid's work already referred to proves that it is felt at even greater distances in the Atlantic :—

"I was in Bermuda when the hurricane of 1839 occurred, and distinctly heard the sea breaking loudly against the south shores on the morning of the 9th September, full three days before the storm reached the island, as recorded in tables of the state of the weather kept at the Central Signal Station. At that time the hurricane was still within the tropics and distant ten degrees of latitude. As the storm approached, the swell increased, breaking against the southern shores with louder roar and great grandeur until the evening of the 12th September, when the whirlwind storm reaching the Bermudas set in there. When the storm had passed over the Bermudas, the southern shore became calm, and the northern reefs, in their turn, presented a white line of surge caused by the undulations rolled back from the storm in its progress towards Nova Scotia and Newfoundland."

It has been pointed out above that a cross or confused swell is due to two or more sets or series of waves produced by different actions and advancing from different directions over the same area at the same time. It may, for example, be due to the interference of waves originating in the inner central storm area with waves due to winds in the outer storm area or beyond the storm area, as for example, the intensified south-west winds to the south of the storm area. As a rule, the area of confused swell is strongest and most marked in the southerly quadrant and least in the western and north-west quadrants.

The following gives a few examples (out of a large number collected) from the logs of vessels of the swell experienced by them during recent cyclonic storms in the Bay, together with data shewing their distance from the storm centre, and the bearing of the storm centre for comparison with the direction

of the swell. It will be seen that they confirm almost without exception the conclusions stated above.

Swell.

Number.	Ship.	Position. Latitude. N.		Position. Longitude. E.		Bearing of the centre.	Swell. Direction.	Swell. Character.	Wind.	Reference.
1	*Sirsa* .	18°	4	87°	41	168 miles N. 80° E.	East-north-east.	Heavy confused.	NW.	Balasore cyclone, page 19.
2	*Chyebassa*	22°	33	88°	31	286 miles S. 23° E.	East .	Confused.	NNE.	Do.
3	*Comet* .	20°	46	87°	40	534 miles S. 17° E.	South-east.	Heavy cross.	S. .	Akyab cyclone, page 16.
4	*Comet* .	20°	46	87°	40	386 miles S. 31° E.	South-east.	Do.	NE.	Akyab cyclone, page 18.
5	*Sirdhana*	16°	35	86°	37	377 miles N. 65° E.	North-east.	Heavy	W. .	Akyab cyclone, page 22.
6	*Comet* .	20°	46	87°	40	296 miles S. 66° E.	South-east.	Heavy cross.	NE.	Do.
7	*Patiala* .	15°	50	93°	53	315 miles S. 65° W.	South-west.	Heavy	SSE.	Cyclone Memoirs, No. V, page 129.
8	*Wildcraft*	11°	55	84°	55	560 miles N. 11° E.	North-east.	Do.	SW.	Cyclone Memoirs, No. V, page 72.
9	*Kerbela* .	Cocanada.				515 miles S. 44° E.	East .	Do.	N. .	Cyclone Memoirs, No. V, page 118.
10	*Canara* .	19°	24	89°	58	190 miles N. 84° W.	South-south-west and west.	Do.	SE. by S.	Monthly Review, June 1892, page 202.
11	*Baghdad*.	Akyab.				300 miles S. 5° W.	South .	Do.	E. .	Marine Report, 28th October 1893.
12	*F. L. V. Torch.*	Eastern Channel.				20 miles S. 5° W.	South-east and south.	High cross.	E. .	Monthly Review, June 1895 page 252.,

Swell—concld.

Number.	Ship.	Position.		Bearing of the centre.	Swell.		Wind.	Reference.
		Latitude. N.	Longitude. E.		Direction.	Character.		
13	*F. L. V. Hesperus.*	Intermediate station.		40 miles S. 72°W.	South .	High .	SE. .	Monthly Review, July 1895, page 305.
14	*Kistna* .	19° 26	93° 32	450 miles N. 79°W.	West .	Heavy	SE. .	Marine Report, 7th Aug. 1895.
15	*F. L. V. Torch.*	Eastern Channel.		50 miles S. 17°W.	South .	Do.	NE.	Monthly Review, August 1896, page 365.
16	*Katoria* .	20° 4	92° 40	285 miles W.	South .	Do.	SE .	Monthly Review, June 1897, page 263.
17	*Mecca* .	16° 57	92° 52	505 miles N. 71°W.	South-west.	High .	S. .	Marine Report, 9th Sept. 1897.
18	*Kohinur* .	15° 49	94° 27	290 miles N. 48°W	West .	Heavy	SW.	Monthly Review, October 1897, page 489.
19	*Malda* .	19° 45	89° 33	180 miles S. 22°W.	South .	Do.	Var.	Marine Report, 29th December 1897.
20	*F. L. V. Torch.*	Mutlah.		260 miles S. 47°W.	South .	Heavy quick.	ESE.	Monthly Review, June 1898, page 280.
21	*Ellora* .	21° 32	88° 6	70 miles S. 70° E.	South-east.	Heavy	NNE.	Monthly Review, August 1898, page 404.
22	*F. L. V. Torch.*	Mutlah		20 miles N. 47°E.	South-south-west.	Very heavy.	NE.	Monthly Review, August 1898, page 404.

It will now be seen that the subject has a most important practical bearing.

It has been shewn that the waves produced by the strong winds of a cyclonic storm pass outwards beyond the storm area, and produce a very observable swell at distances of 400 and 600 miles away from the centre. I have, however, not been able to ascertain whether any accurate measurements have ever been made of the rate of motion of the cyclonic swell in the Bay of Bengal. The swell, so far as I can estimate, advances across the Bay with an average velocity probably considerably exceeding 25 miles per hour, or much greater than that at which the storm advances. And hence frequently the first sensible indication of a distant but approaching cyclonic storm on the Bengal or Madras coast is the increasing swell which may be felt from one to three days before the arrival of the storm, and the way in which it increases in force affords to those who have some acquaintance with the character of the swell, sea, etc., on that part of the coast, a fair estimate of the extent or intensity of the approaching cyclone.

It is a very simple indication, but it is, I believe, a very valuable one, and it is much to be wished that greater use were made of it, and that fuller data were forthcoming in order to test the conclusions stated above and also, if found possible, to make them more definite and precise.

Set at the Head of the Bay.—One important indication at the head of the Bay (and more especially at the Sandheads), of unsettled weather in the centre or north of the Bay is the set or current which commences almost with the disturbance and increases with it. In consequence of the peculiar shape of the Bay (converging and contracting northwards), and of the shallowness of the water over a considerable area near the head of the Bay, and of the large quantities of fresh water brought down by the Ganges and Megna, the currents at and near the head of the Bay are always considerable, but in ordinary weather shift with the tides. The strong southerly winds which prevail for some time before a whirl has been definitely formed, and also during its existence, appear to give, in the south and centre of the Bay, by surface friction, a general north-easterly impetus to the water, which, north of Diamond Island, is converted into a coast current that is deflected near the head of the Bay, and gives rise to a steady set or drift to the west. If a cyclonic storm has formed in the centre or north of the Bay and moves in a west or north-west direction to the Orissa or Bengal Coast, the rotatory air-motion sets up a similar, but of course much feebler, rotatory motion of the water-surface in the centre and north of the Bay, and hence also gives a westerly motion to the water at the head of the Bay. Consequently, the westerly increasing set of the water at the head of the Bay is a marked and characteristic feature of the antecedent weather which favours cyclone formation, as well as of the cyclone itself. It is probable that the strength of a cyclone advancing to the north-west coast of the Bay could be roughly ascertained by the strength of the westerly set at the head of the Bay. Data are, however, wanting to test this. Innumerable examples of the

westerly drift or current might be given from recent information sent in by ships. A few will suffice.

The log of the P. V. *Coleroon* for the 14th June 1886 (just before she experienced the cyclone of June 12th to 16th) remarks: " There was a strong westward set during the day. " The *City of Bombay*, which was approaching the mouth of the Hooghly on the morning of the 15th, had a strong west-northwest current. The log of the *Scottish Chieftain*, in Lat. 20° 50′ N. and Long. 88° 10′ E. on the 28th June, during another small storm of the rains, remarks that she had a very strong westerly current, and on the 30th June when in Lat. 20° 32′ N. and Long. 87° 34′ E. states: " We still experience a very strong westerly set." The *Moulmein*, in the storm of 21st September 1878, experienced at the head of the Bay a strong current setting westerly about 2½ knots per hour.

Currents in cyclonic storms in the Bay of Bengal.—In the preceding paragraphs it has been briefly explained how the cyclonic winds, by friction with the surface-water, &c., may give rise to strong currents in the Bay of Bengal. Near the coasts the directions of the currents are largely modified. In the open sea the currents over the whole storm area of fierce and hurricane winds approximately agree in direction with the winds, and are probably stronger than are generally imagined. The drift near the centre of large storms in the Bay of Bengal may be as much as 6 to 8 knots or miles per hour, and mariners should be prepared for a drift of this magnitude in the larger cyclonic storms in the Bay.

The following are a few of the more remarkable instances of strong currents during cyclonic storms in the Bay during the last few years, and shew that the estimate given above is probably not too large:—

Ship.	Date.	Position.		Direction and amount of current.
		Lat.	Long.	
Ballaat . . .	9th November 1886.	10¾° N.	81¾° E.	Current during 72 hours S. 8° E., 150 miles.
Airlie . . .	21st November 1886.	15° N.	92¾° E.	The ship was found to be 130 miles to north-west by west of her position by dead reckoning after allowing 4 knots for dead drift during the cyclone. (The last preceding observation was taken 48 hours before.)
Argo . . .	28th November 1886.	Madras Roads .		Extraordinary strong north current near Madras—4 to 5 knots.
Satara . . .	14th November 1883.	16¾° N.	94° E.	A current set the ship from noon of 11th to noon of 14th N. 13° W., 171 miles.
Satara . . .	15th November 1883.	16° N.	95¾° E.	Current during the previous 24 hours W., 65 miles.
Bancoora . . .	30th June 1883.	20° N.	88½ E.	Current 80 miles adverse.

Ship.	Date.	Position.		Direction and amount of current.
		Lat.	Long.	
Moulmein . .	21st September 1878.	On voyage from Calcutta to Chittagong.		Experienced a strong current setting westerly about $2\frac{1}{2}$ knots per hour.
Akbar . . .	6th November 1886.	$9\frac{1}{2}°$ N.	$90°$ E.	She was in the outer gale circle of cyclone, and yet the current which she experienced during the previous 24 hours had carried her (if her log may be trusted) 160 miles to the N. 70° E. or at a rate of between 6 and 7 miles per hour.
Ireshope . . .	16th October 1874.	$20\frac{1}{2}°$ N.	$88\frac{1}{2}°$ E.	A strong current setting to south-west 5 miles per hour.
Belfast of Liverpool .	8th October 1882	$20\frac{1}{2}°$ N.	$87\frac{1}{2}°$ E.	Strong south-westerly current running against which the ship could make no progress.
Do. .	9th October .	$20\frac{1}{2}°$ N.	$87\frac{1}{4}°$ E.	Found current running between south-south-west round to north-west from $1\frac{1}{2}$ knots to 3 knots per hour.
Do. .	10th October .	$20\frac{1}{4}°$ N.	$87\frac{1}{4}°$ E.	Current running very strongly to the south-west.
Do. .	11th October .	$20\frac{1}{4}°$ N.	$87\frac{1}{4}°$ E.	Strong south-south-west current changing to south-west, west-south-west, and north-west.
Nith . . .	8th October 1882	$20\frac{1}{2}°$ N.	$87\frac{3}{4}°$ E.	South-west to west-south-west current, 35 miles.
Do. . . .	11th October 1882.	$20°$ N.	$87\frac{3}{4}°$ E.	Very strong south-west current.
Do. . . .	14th October 1882.	$20°$ N.	$89\frac{1}{2}°$ E.	Current west-south-west, 48 miles.
P. V. *Coleroon* .	22nd September 1885.	Sandheads near the mouth of the Hooghly.		During day and preceding night there was some 4 to 5 knots set to westward.
Bhandara . .	31st October 1888.	Madras Harbour.		Strong southerly current.
Gilroy . . .	28th October 1888.	$20°$ N.	$88\frac{1}{2}°$ E.	Current so strong that ship would not answer helm.

Hence it may be assumed that the currents may vary from 2 to 3 knots in the outer storm area to 6 to 8 knots in the inner storm area, and that near the head of the Bay the currents may even be stronger than this. If a mariner be caught in a cyclonic storm near the head of the Bay, he should, in shaping his action and course, take carefully into consideration the fact of the strength of the storm currents at the head of the Bay and in the inner storm area, and of their direction as determined by the position of the storm and the shape and conformation of the Bay.

The eye of the storm.—One of the most remarkable features of the more severe cyclones of the tropics is the area of very light winds, or absolute calm in the centre of the storm. Over this area the torrential rain of the hurricane ceases, and the clouds frequently break away, showing blue sky, with the sun or the moon and stars. On account of its peculiar clearness this spot has received the name "the eye of the storm."

The eye of the storm is a calm area varying very largely in diameter, but rarely exceeding 15 to 20 miles in diameter, characteristic only of the most violent class of tropical cyclones. Immediately outside this central area of these cyclones the wind is indescribably furious and the rain falls in torrents. The transition from the hurricane winds immediately outside the central calm area to the calm area is usually very sharp, the passage as a rule being a matter of a few minutes only. The eye is sometimes an area of light breezes, but more commonly of absolute calm, without rain, and often with blue sky. The cross sea, however, is very violent and dangerous. Birds and sometimes butterflies have been found in the centre, usually in an exhausted state.

Five detailed accounts have been selected of the weather and sea experienced in the calm areas of four different storms or cyclones in the India and China Seas and are given below. The first instance is that of a tug in the Calcutta cyclone of 1864.

"The '*Alexandra*' steam tug was at anchor off Saugor light-house on the early morning of the 5th. At 4 A.M. the wind shifted suddenly to north-east, blowing in furious gusts, accompanied by pelting sleet and seas over all. On coming head to wind the engines were set going at full power; about 8 A.M. or 9 A.M. it became suddenly calm, with a heavy confused sea, the sun appearing at the turn for a few minutes. The calm interval lasted about three-quarters of an hour, the steamer's head to wind and the engines doing their best. During the calm, being apparently in the vortex of the hurricane, several land birds were falling about the decks,—some dead. At the end of the calm, a thick mist and heavy rollers seemed coming from north-west, accompanied by a moaning sound, which was immediately followed by a sudden blast from the north-west, throwing the steamer on her beam ends, and burying her in a sheet of foam to the top of the funnel."

The second description is that giving an account of the passage of the ship "*Idaho*," through the calm centre in a hurricane in the China Sea, September 21, 1869.

"Suddenly the mercury rose (from 27·62″ to 27·90″), and with one wild, unearthly, soul thrilling shriek the wind as suddenly dropped to a calm, and those who had been in these seas before knew that we were in the terrible *vortex* of the typhoon, the dreaded centre of the whirlwind.

"Till then the sea had been beaten down by the wind, and only boarded the vessel when she became completely unmanageable; but now the waters, relieved from all restraint, rose in their own might. Ghastly gleams of lightning revealed them piled up on every side in rough, pyramidal masses, mountain high,—the revolving circle of wind, which everywhere inclosed them, causing them to boil and tumble as though they were being stirred in some mighty cauldron. The ship, no longer blown over on her side, rolled and pitched, and was tossed about like a cork. The sea rose, toppled over, and fell with crushing force upon her decks. Once she shipped immense bodies of water over both bows, both quarters, and the starboard gangway at the same moment. Her seams opened fore and aft. Both above and below, men were pitched about the decks and many of them injured.

"At twenty minutes before eight o' clock the vessel entered the *vortex;* at twenty minutes past nine o' clock it had passed and the hurricane returned blowing with renewed violence from the north, veering to the west. The ship was now only an unmanageable wreck."

The third account is from the log of the steamship "*Inchulva,*" which encountered the Aden cyclone in the Arabian Sea, May 29, 1881:

"We consider ourselves in the north-west quadrant, with the centre coming up from the south-east so fast there is no time to dodge it. So we prepare for the dreaded centre to pass over us. The wind increases much, as it advances. The sea cannot rise. We notice the most from the east and south-east. Noon—A terrific wind still at north-east, steady. Away goes fore-gaff, and fore-trysail, hatches, in fact every thing the wind can reach, blows to atoms. 2 P.M., the centre passes over us. During this time it is calm, with a fearful boiling sea. The clouds hang heavy to the south-west. Sun's limb clearly visible through thin yellowish haze; also several stars, at least a dozen(?). 2-40 P.M. wind light from south-west; in a few minutes the cyclone has increased in force to a greater extent than that part of the storm at north-east; rain falls in torrents. We see many land birds and butterflies and whales in the centre. We employ ourselves during the calm interval clearing up the wreck and getting on hatches. As soon as the wind goes to south-west, the barometer rises and continues so to do as the centre passes away from us."

An experience of considerable meteorological importance, on account of the observations taken, was that at Manila, October 20, 1882. The following extract gives the facts relating to the calm in the eye of the storm :—

"At 11-46 A.M. (20th), after a violent rush from the west-north-west, Manila was in the vortex. The calm was not absolute, but with alternate gusts and lulls for about eight minutes. At 11-52 A.M. the calm was absolute for two minutes; then alternate calm and gusts from the south-west. Blue sky was not seen, but it cleared to a dense, watery vapour; the dark belt of the storm could be traced on the horizon. The diameter of the vortex was probably not more than fourteen or sixteen miles.

"The most striking phenomenon of the calm centre was the sudden change of temperature and hygrometric condition of the air, as revealed by the curves traced; the former from seventy-five degrees to eighty-eight degrees Fahrenheit (*i.e.*, seventy-five degrees before passage of centre, eighty-eight degrees during passage, and seventy-five after), and the latter from fifty-three (rarely observed here and only in April and May,) up to saturation (*i.e.*, saturation before and after passage, fifty-three during passage). Persons who opened their windows during the calm were instantly compelled to close them, for the air 'burned,' as in the Italian Sirocco."

The following is from a report by Captain P. Duhme, Master of the S.S. "*Taicheong*," of a hurricane experienced off Formosa, July 17, 1891.

"In order to avoid running straight into the centre I had the ship headed north-east into the prevailing sea, which manœuvre was executed without accident. At 11-15 P.M. the wind suddenly moderated and backed to north-north-west, the sky cleared, the moon and stars becoming visible, a few sea birds anxiously fluttered about the ship. Until twelve o' clock there was a gentle north-west breeze, and then the smoke from the smoke pipe was suddenly driven from south-west. The engine having worked slowly only for some time, I immediately rang full speed and brought the ship's head to south-west. The wind increased rapidly from south-west, the barometer rose, and about fifteen minutes after the almost calm region had passed the ship, the south-west wind was blowing with indescribable violence. Under full power the ship headed south-west by south in comparative comfort and escaped all damage. The south-west wind decreased slowly."

These descriptions give a general idea of the winds, weather, and sea usually experienced in the eye of the storm.

The following six paragraphs give a summary of the available information relating to the calm centre of cyclones in tropical seas.

The central calm is most characteristic of tropical cyclones. It has seldom

been reported from cyclones originating in temperate latitudes. Cyclones originating within the tropics may, however, move poleward into the temperate zones carrying their characteristic centre with them.

As the storm centre moves towards the observer, the wind is steady in direction, blowing nearly at right angles to the path of the storm. There is a heavy rain, usually accompanied by lightning and thunder. Just before the passage of the central calm the hurricane is at its height. Captains of vessels report the wind as indescribably furious. Everything on deck the wind can reach is blown to pieces. In several instances the boat at the weather davits has been torn from strong fastenings and carried clear over the ship. In short, we have reports of winds as severe as any vessel could live through; and beyond that we can only conjecture, from the great number of ships "last seen" near the storm centre, how much more violent the hurricane may be.

In the majority of cases reported the ship passes almost instantaneously from the most frightful hurricane into absolute calm. Occasionlly, however, after the first abrupt lull, the wind dies away gradually, so that it may be ten minutes or more before there is a perfect calm.

The calm is usually described as complete, making all allowance for effect of the contrast with the preceding gale, and there seems no reason to suppose that, in most cases, there is any appreciable motion of the air.

The descriptions given previously in detail, including those of the "*Alexandra*" and "*Inchulva*," mention the fact of the sun or stars being seen during the central passage. In other cases there was a thick haze during the calm. The clearing of the sky overhead, either wholly or partially, is one of the most marked features of the centre. The heavy rain of the hurricane ceases, and the sky clears either to pale blue sky with the sun or stars visible, or to a haze. Some characteristic reports are as follows :—

> "A lull, the weather cleared up, with clear sky overhead, but round the horizon all dark."
> "The sun shone at intervals during the calm."
> "The wind suddenly moderated and backed to north-north-west, the sky cleared, the moon and stars becoming visible."

All reports agree that the calm centre is, roughly speaking, the lowest point of barometric depression in the hurricane. As to how the barometer varies during the interval of the calm passage, the accounts are meagre and unsatisfactory.

Distribution of cyclones according to season.—The next important subject to be dealt with is the origin and line of march of cyclones in the Bay of Bengal as determined by the season.

In the first place theory suggests, and experience confirms, the principle that cyclonic storms do not form over or near the equator. Squally weather with strongish gusts of wind during the squalls is by no means unusual, but these squalls never form part of a cyclonic circulation or whirl. All experience

shews that they are only breaks or interruptions of comparatively brief duration in the ordinary weather of the season, and that they do not form part of a large and rapid eddying motion of the air, such as constitutes a cyclone. There is no record during recent years of a storm having formed to the south of Lat. 8° N., and it *may be accepted as a general principle that the lowest latitude in the Bay at which cyclonic storms are formed or met with is Lat. 8° N.*

The continued accumulation of cyclone records shews that the one feature which appears to be absolutely essential to the formation of a large cyclonic whirl or revolving storm in the Bay is an inrush of moist southerly winds. Such inrushes take place occasionally before the permanent setting in of the south-west monsoon. Hence cyclonic storms may occur at any time during the period when the south-west monsoon current blows steadily, and also during the period in which brief advances of south-west winds may occur over the south or the whole of the Bay at the commencement of the south-west monsoon, and hence at any time during the period April to December. They are rare in the limiting months April and December. *Hence it may be assumed that storms may occur at any time during the period May to November, and under exceptional circumstances in April and December.*

Another equally important principle or generalization is, that almost all cyclones that occur in the Bay are generated in the Bay. Three storms have passed from the Gulf of Siam across the Malayan Peninsula into the Bay during the past 25 years. There is not a single example on record of a cyclonic storm having formed in the Arabian Sea and passed across India into the Bay of Bengal. On the contrary, at least three storms which originated in the Bay of Bengal, during the past 15 years passed across India and gave rise to stormy weather in the Arabian Sea for some days. The fierce storm of November 2nd to 15th, 1886, which originated near the Andamans and passed over Madras and advanced across the Peninsula and the Arabian Sea to the entrance of the Persian Gulf, may be cited as an example. The P. and O. Steamer *Peshawar* was involved in it in Lat. 16½° N. and Long. 60° E., and the S. S. *Mobile* (proceeding from Bushire to Bombay) in Lat. 23½° N. and Long. 62° E.

Hence almost all cyclonic storms in the Bay of Bengal (at least 49 out of 50) originate or are produced in the Bay itself.

The Bay of Bengal has thus the peculiar advantage of being a small isolated meteorological area. Its geographical position and features constitute it into a self-contained area in this respect. It is thus of special interest, as the process of storm generation, on either the large or small scale, may be observed in it from the very earliest stages. And with the growth of knowledge on the part of the Meteorological Department, and of skill on the part of the sailor, there is no reason why a ship, and still less a steamer, should ever be involved in the inner or dangerous portion of a severe cyclonic storm in the Bay.

During the past 25 years (since the establishment of the India Meteorological Department in 1875), some 211 cyclones of all degrees of magnitude have been observed and recorded, from the intense Backergunj cyclone down to the feeble but frequent whirls of the months of July and August.

The charts (Plates XXVII and XXXVI) give the place of origin so far as is known of these cyclones. These charts will repay ample study. The condensation theory indicates that the conditions favouring the formation of a cyclone may occur in any part of the Bay during the whole period that the south-west monsoon current prevails in any portion of it. The charts confirm this inference most clearly. Hence it is well that the mariner should not accept unreservedly such statements as that cyclones originate only in certain portions of the Bay, as for instance, to the west of the Andamans, etc. He must in fact separate completely in his mind what is probable from what is possible.

Hence it may be laid down as a rule that cyclones or cyclonic storms can originate in, or advance over, any part of the Bay to the north of Lat. 8° N. near the coast or in the centre of the Bay or the Gulf of Martaban during the months of April to December.

There is a belief that the area to the west of the Andamans possesses certain peculiarities which favour the origin of fierce cyclones. This opinion is so widely spread that it is in newspapers, etc., frequently referred to as the birthplace of cyclones in the Bay. The only special feature is that this area is near the centre of the sea or water-surface comprising the Gulf of Martaban and the Bay of Bengal. Cyclones forming near the Andamans have hence a longer path before they reach land than if they originated nearer to the coast, and hence, if the conditions are favourable, are more likely to develop into large and dangerous cyclones. This appears to be the main reason why the cyclones that form in that part of the Bay are larger and more intense than those formed near the head of the Bay, and are on the whole the most violent of all storms experienced in the Bay.

Experience shews that cyclonic storms and cyclones (more especially the latter) usually increase in intensity as they approach the coast, and that the lowest pressures are recorded in the calm centre shortly before reaching land. Hence the danger of being caught in a cyclone near the coast is increased by the exceptional strength of the storm when approaching it. The dangerous quadrant in cyclonic storms is the right advancing quadrant, and hence in the great majority of storms in the Bay of Bengal, it is the western or northwestern quadrant.

The following paragraphs give a full statement of what is known of the distribution of cyclonic storms in the Bay of Bengal during the cyclone season, April to November, and is illustrated by storm track charts given at the end of the book. The principles stated in the present section are of much importance.

A brief inspection of the storm track charts (Plates XXI to XXVI and XXVIII to XXXV) will shew that the storms of the Bay of Bengal are much more regular in their occurrence and track than might at first sight be supposed. It is very desirable that the sailor in the Bay of Bengal should recognize these general laws of distribution of cyclonic storms in that area, as each inference, statement or law represents a large amount of accumulated experience, and tells him when and where he may expect to meet storms in the Bay, and also the chance of their occurrence and their probable character and track at any given time. Thus, by an inspection of the charts, the reader can ascertain for any month—

1st.— In what part of the Bay he is likely to meet with a cyclonic storm, and in what part cyclonic storms rarely or never occur at that time.

2nd.— What is the usual track or tracks of cyclonic storms which form or appear during the month in the Bay.

Another important point, but which cannot be ascertained directly from these charts, is what are the chances that a storm forming in any month will be of moderate or great intensity (that is, whether it will be a cyclonic storm or a cyclone).

In the event of encountering squally weather in the outskirts of a cyclonic storm, the reader will, by means of this information, be enabled to decide, independently of wind indications, the probable position and track of the storm he may encounter in the Bay so far as it depends upon the time of year. If the wind indications confirm this, he will at once recognize that the storm is of the character and kind normal to the season. If it occurs in a different portion of the Bay or is moving in a different manner than is usual, he will be at once prepared for the fact that the storm is of a different character from those normal to the season, and will in such a case make even more exact and careful estimates of its position and track, and take greater precautions than he would do in the first case. The chances of a storm being normal in character appear to be about ten to one. Hence these laws about to be stated are, like many of the laws, principles or rules, upon which man is compelled to act, mere summaries of past experience which afford a probable and useful, but not a certain and infallible, guide for action.

The sailor, like the meteorologist, must hence carefully remember that, although the weather conditions which give rise to storms are fairly regular in character, and subject to laws which are now known more or less exactly, it is possible that very exceptional conditions may occur at distant intervals and give rise to storms of exceptional origin, intensity, course, &c.

The storm track charts given in Plates XXI to XXVI, Plates XXVIII to XXXIII and Plates XXXVIII to XLV consist of three series. The first series (Plates XXI to XXVI) give the tracks of all cyclonic storms which have

formed in the Bay of Bengal during the eleven years 1877-87 and have had an existence on land of at least 24 hours after crossing the coast. The tracks of the storms of the first five years of this period are filled in chiefly from the land observations, as meteorological data from ships in the Bay were not available in the majority of cases. Hence the tracks of these storms in the Bay are to some extent doubtful. They may, however, be accepted as approximately correct. The second series of charts (Plates XXVIII to XXXIII) are based on the information which has been systematically collected from vessels entering the port of Calcutta during the twelve years 1888—99, and have been prepared in the same manner and form as the preceding. The third series including Plates XXXVIII to XLV shew the tracks of all storms during the period 1882-99 in which winds of force 8 and upwards were actually experienced by vessels. It is probable that these track charts furnish an approximate estimate, month by month, of the laws of occurrence and distribution of what may be termed the more dangerous storm in the Bay of Bengal in which winds of great to excessive violence prevail.

The first and second series of charts are given for the information of all who study storms, with a view to endeavour to ascertain their distribution, &c. The third series Plates XXVIII to XLV are intended chiefly for sailors who are naturally anxious to utilize any aids they can have to avoid those storms which may involve them in stormy weather and dangerous winds in the Bay of Bengal.

The following are the more important facts with respect to storm occurrence and distribution in the Bay of Bengal, derived in part from an examination of these charts, and in part from the lists of storms given in the "Weather charts of the Bay of Bengal, and adjacent seas north of the Equator," compiled by Mr. Dallas, First Assistant Meteorological Reporter to the Government of India.

April.—It has already been pointed out that cyclonic storms never occur in the Bay unless humid south-west winds (*i.e.*, the winds of the south-west monsoon) are blowing over the south of the Bay at least. These winds do not set in permanently until the middle or end of May, but previously to that date, south-west winds occasionally advance northwards for a brief period across the entrance of the Bay as far north as the Tenasserim coast and the south or centre of the Bay and then retreat again. These occasional bursts of south-west winds may occur at any time during the month of April, but are most probable in the latter part of the month. Sometimes these advances, if unusually powerful, give rise to cyclonic storms. The storms of April and also of the first fortnight of May, which form under similar conditions, to those of April (*i. e.*, during partial or irregular advances of the south-west winds over the south of the Bay) usually originate to the west or west-north-west of the Nicobars, and advance in a west-north-west direction to the Madras coast.

No storms occurred in April during the period 1876 to 1892. Four storms, three of which formed near the Andamans were experienced during the month in the period 1893-99. Three of these storms ad vanced to the South Burma Coast and one to the Arakan Coast. The following is the list of all known or recorded storms in the Bay in the month of April :—

13th April 1749.—A furious hurricane on the Coromandel Coast.

27th April to 1st May 1840.—A cyclone crossed from the Andamans to the Orissa coast ; the centre passed just south of Puri.

23rd April 1848.—Violent hurricane off Ceylon.

23rd to 28th April 1850.—A cyclone formed to the west of the Nicobars and passed northwards to Bengal.

21st to 23rd April 1854.—Violent hurricane in the Gulf of Martaban.

9th and 10th April 1858.—Cyclone passed from the Andamans to Cape Negrais, and thence into Lower Burma.

21st to 27th April 1859.—Gale over the Bay of Bengal and Andaman Sea. It was most violent in the neighbourhood of Negapatam.

6th to 11th April 1860.—Cyclone formed over the centre of Bay to the westward of the Nicobar Islands.

22nd April 1875.—Cyclone off the Coromandel Coast.

25th to 27th April 1893.—Feeble cyclonic storm advanced from the neighbourhood of the Andamans across the Burma Coast to west of Rangoon.

27th to 30th April 1894.—Cyclonic storm of considerable intensity advanced from the Andaman Sea across the Burma Coast near the mouth of the Rangoon river.

23rd to 26th April 1895.—Very severe cyclonic storm advanced from the south of the Bay in a northerly direction, recurving to north-east, and crossed the Arakan Coast to the north of Akyab.

28th April to 2nd May 1899.—Cyclonic storm of moderate intensity advanced from the neighbourhood of the Andamans across the Burma Coast near Diamond Island.

Of these thirteen cyclonic storms, four travelled westwards to the Ceylon or Coromandel Coast, five formed in the Andaman Sea and advanced northwards into Lower Burma and one formed in the south of the Bay and advancing first to north and then to north-east passed across the Arakan Coast near Akyab. The remaining three marched in a north-north-west direction to the Bengal and Orissa Coasts.

Hence cyclonic storms are of comparatively rare occurrence in the Bay of Bengal in April. They form either in the south of the Bay or in the Andaman Sea. Those which form in the Bay proper are generated to the west of the Nicobars or Andamans, and march (in at least three cases out of four) in a

west or west-north-west direction to the Ceylon or Coromandel Coast. Those which originate in the Andaman Sea march northward to the Lower Pegu Coast. Storms are somewhat less probable in this month in the Andaman Sea than in the Bay of Bengal.

May.—This month not only witnesses occasional irruptions of south-west humid winds over the south of the Bay, but also in normal years the permanent advance of the great monsoon current into the Bay which usually occurs in the third or fourth week of the month. Hence cyclonic storms are a characteristic feature of the weather of the month, and are occasionally of exceptional strength and violence. If they form in the first fortnight, they are almost invariably due to a temporary advance of these winds, and hence originate in the south of the Bay or the Andaman Sea. In the former case they usually march in a west-north-west direction to the Coromandel Coast or by a curved track to the Arakan Coast. If they are generated during the great advance of the monsoon current in the latter half of the month, they generally form in the centre of the Bay, and advance in some northerly direction towards the coast of Bengal or Orissa. The following gives a list of the cyclonic storms whose tracks are given in the track charts of the month (Plates XXI, XXVIII, and XXXVIII) :—

May.

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1877	12th to 22nd May .	W.N.W. to N.N.W.	Coromandel Coast .	Severe cyclonic storm.
1879	19th to 24th „ .	W.	Coromandel Coast to the north of Madras.	Ditto ditto.
1879	29th May to 2nd June.	W.N.W.	Balasore Coast .	Feeble ditto.
1881	26th to 28th May .	N.N.W.	Bengal Coast near Saugor Island.	Ditto ditto.
1884	13th to 17th „ .	N. to N.E.	Arakan Coast .	Intense ditto.
1886	22nd to 24th „ .	W.N.W.	Coromandel Coast near Negapatam.	Feeble ditto.
1887	21st to 28th „ .	W.N.W. and N.W.	Orissa Coast near Balasore.	Intense ditto.
1888	10th to 13th „ .	W. by N.	South Coromandel Coast between Cuddalore and Negapatam.	Feeble ditto.
1890	5th to 8th „ .	N.N.W. and N.N.E.	Arakan Coast to south of Sandoway.	Severe ditto.
1893	21st to 29th „ .	N.	Bengal Coast, west of Saugor Island.	Very severe ditto.
1897	11th to 13th „ .	N.	Burma Coast near Rangoon.	Feeble ditto.
1898	5th to 8th „ .	N.W. thro'. N. to N.E.	Arakan Coast near Chittagong.	Severe ditto.

Twelve cyclonic storms occurred in this month during the 23 years 1877—99. Seven of them were storms of great intensity and accompanied with hurricane winds. Four advanced in a west-north-west or north-west direction to the Coromandel Coast, one in a west direction to the Orissa Coast, and the remaining seven in northerly directions to the Burma, Arakan or Bengal Coast at the head of the Bay.

Hence it is practically an even chance that if a cyclonic storm forms in the Bay in this month, it will be of great intensity (or a cyclone). If it forms during the first fortnight, the chances are about four to one that it will advance in a west-north-west direction to the Coromandel Coast, but if it forms during the last fortnight the probabilities are nearly two to one it will march in a northerly direction to the head of the Bay.

The following is a list of all storms in this month recorded previously to the year 1877 :—

19th to 20th May 1787.—Great storm at Coringa.

3rd May 1811.—Great storm at Madras, which destroyed nearly every vessel in the roads.

8th May 1820.—Cyclone at Madras, which crossed the Peninsula.

26th May 1823.—Gale passed from the north of Bay over Balasore.

7th to 10th May 1827.—Gale at Madras.

26th May 1830.—Cyclone passed northward up the Bay into Bengal.

21st May 1832.—Storm in Gangetic Delta.

21st May 1833.—Storm at the mouth of Hooghly.

May 1840.—Hurricane off Madras and southern coast.

16th May 1841.—Cyclone passed from the south-west of the Andamans to Madras.

31st May to 5th June 1842.—Great cyclone in Calcutta on 3rd June—the most severe gale ever felt in Calcutta ; centre passed over the city.

19th to 23rd May 1843.—Cyclone passed from south of the Bay northward to Ongole.

11th May 1844.—Gale at Noakhally and Chittagong.

12th and 13th May 1849.—Gale at Chittagong.

30th April to 6th May 1851.—Cyclone passed from the north-east of Ceylon to Madras ; passed to the northward of the town.

12th to 15th May 1852.—Cyclone started in latitude 15° and marched due north to the Sunderbans, the centre passing 39 miles east of Calcutta.

15th to 29th May 1855.—Cyclone over the centre of Bay.

15th to 20th May 1858.—Gale formed over the centre of Bay, and passed across the Coromandel Coast.

1st May 1869.—Cyclone in the north-east of the Bay.

13th to 17th May 1869.—Cyclone passed from Cape Negrais north-westward to Bengal.

28th to 30th May 1870.—Cyclone in the north-east of the Bay.

1st to 3rd May 1872.—Severe cyclone formed in about latitude 7° 30′ N. and passed north-westward to Madras.

1st to 5th May 1874.—Cyclone originated near latitude 9° N., longitude 85° E.; and travelled north-westward towards Madras, but did not reach land.

10th to 13th May 1876.—Cyclone formed to the west of the Ten Degree Channel; travelled slowly northward.

This list gives 24 storms: 15 of these formed during the first fortnight of the month, of which 10 marched in a westerly direction to the Madras Coast. Seven certainly formed during the last fortnight, of which at least five advanced in a northerly direction to the head of the Bay. The tracks of three of the storms are not sufficiently indicated to allow them to be classified. It will thus be seen that these facts agree very closely with those given in the preceding paragraph. The following conclusions are derived from the whole of the storm data of the month :—

The preceding data establish that cyclonic storms are of comparatively frequent occurrence in the Bay during May (about two every three years). If they originate in the first fortnight of the month the chances are about three or four to one they will march in a westerly direction to the Coromandel Coast; but if during the latter half of the month the chances are three or four to one they will march northwards to the head of the Bay. It is also about an even chance that a storm forming in this month will be of great intensity (i.e., *a cyclone*).

June.—The south-west monsoon is usually established early in the month over the whole of the Bay. This fact at once suggests that the cyclonic storms of the month in the Bay generally form near the head of the Bay. A reference to the track charts of the month (Plates XXII and XXIX) shews that fourteen storms occurred in this month during the period 1877—87 and twelve during the period 1888—99. Twenty-four of these 26 storms formed to the north of latitude 18° N., and the great majority of them to the north of latitude 20° N. Seven out of these storms advanced in a northerly direction into Bengal or Bihar across the Bengal or North Orissa Coast. One formed to the west of the Andamans and advanced to the Ganjam Coast. The remaining eighteen marched in westerly directions across the Orissa Coast into the Central Provinces, or in west-north-west directions into Upper India (*i.e.*, the Punjab and North-Western Provinces). One of these eighteen storms advanced across the whole length of the Peninsula, and passed out into the Arabian Sea.

The following gives the list of these twenty-six storms :—

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1880	1st to 4th June .	N.N.W.	Bengal Coast near Saugor Island.	Feeble cyclonic storm.
1880	25th to 30th „ .	W. to N.W.	Orissa Coast near Puri.	Ditto ditto.
1881	1st to 5th „ .	N.	Bengal (Sunderbans) .	Ditto ditto.
1881	5th to 9th „ .	W.	Orissa Coast . .	Ditto ditto.
1881	13th to 19th „ .	N.W.	Balasore Coast . .	Ditto ditto.
1883	14th to 19th „ .	N.N.W.	Ditto . .	Moderate ditto.
1883	25th June to 4th July .	N.W. and W.N.W.	Orissa Coast . .	Severe ditto.
1884	18th to 24th June .	W.	Ditto . .	Feeble ditto.
1884	28th June to 6th July .	N.W.	Ditto . .	Ditto ditto.
1885	16th to 25th June .	N.	Bengal Coast . .	Severe ditto.
1885	25th to 29th „ .	N.W.	Balasore Coast . .	Feeble ditto.
1886	14th to 22nd „ .	N. to N.W.	Bengal Coast near Saugor Island.	Severe ditto.
1887	11th to 15th „ .	W.	Ganjam Coast . .	Moderate ditto.
1887	19th to 21st „ .	N.	Bengal Coast near Saugor Island.	Feeble ditto.
1889	9th to 14th „ .	N.	Bengal Coast to west of Saugor Island.	Moderate ditto.
1889	24th to 30th „ .	W. by N.	North Orissa Coast .	Ditto ditto.
1890	17th to 21st „ .	W. by N.	Orissa Coast near False Point.	Feeble ditto.
1892	8th to 13th „ .	N.W.	Orissa Coast near Balasore.	Cyclone.
1893	11th to 18th „ .	W.N.W.	Circars Coast between Vizagapatam and Cocanada.	Feeble cyclonic storm.
1894	20th to 29th „ .	N.W.	Orissa Coast between False Point and Balasore.	Moderate ditto.
1895	19th to 21st „ .	W. by N. .	Orissa Coast near False Point.	Feeble ditto.
1895	26th June to 2nd July .	N.W.	Orissa Coast near Balasore.	Moderate cyclonic storm.

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1896	17th to 23rd June .	N.	Bengal Coast east of Saugor Island.	Moderate cyclonic storm.
1896	25th June to 2nd July .	N. N. W.	Bengal Coast between Saugor Island and Barisal.	Considerable ditto.
1897	15th to 20th June .	W. N. W.	Orissa Coast north of False Point.	Moderate ditto.
1898	12th to 20th ,, .	N.	Orissa Coast near Puri.	Ditto ditto.

Hence the experience of the twenty-three years 1877—99 shews that cyclonic storms in June form almost invariably in the north of the Bay to the north of latitude 18° N., and generally to the north of latitude 20 °N., and that the chances are almost even that they will advance in a northerly direction to the Bengal Coast or in a westerly direction to the Orissa Coast, south of Balasore.

The following is a list and brief statement of the storms of the month in years previous to 1877 of which there are brief records :—

June 1822.—Storm swept over Barisal.

2nd June 1823.—Storm at Chittagong and in the Delta of the Ganges.

8th June 1824.—Heavy storm at Chittagong.

3rd to 5th June 1839.—Storm traversed the head of the Bay from south-east to north-west.

18th to 30th June 1857.—Cyclone formed over centre of Bay ; apparently travelled north-westward towards Orissa.

12th to 17th June 1859.—Gale off Akyab.

16th to 26th June 1863.—Cyclone formed near Acheen Head.

5th to 10th June 1869.—Cyclone generated over the north of the Bay and passed over Bengal.

28th June 1872.—Small storm generated over the north of the Bay and passed over Balasore.

10th to 13th June 1873.—Small storm formed off the Coromandel Coast and apparently travelled northwards.

15th to 17th June 1874.—Small cyclone in the north-west of the Bay.

Of the eleven storms given in the preceding list, five advanced northwards into Bengal and four in a north-west or west direction across the Orissa Coast. The remaining two were very exceptional in character. None of these storms was of excessive violence. They were all in fact cyclonic storms of somewhat greater intensity than usual, or striking examples of the class of storms which are now known to be of comparatively frequent occurrence at the head of the Bay

in June. The law of distribution, as indicated by this list, is practically identical with that of the previous list of storms in June 1877—99. Hence we have the following rule :—

Cyclonic storms are of frequent occurrence in the north of the Bay in June. They usually form to the north of latitude 19° N., or quite at the head of the Bay. One or two such storms may be expected every year. It is an even change whether a cyclonic storm which has formed in the Bay in June will pass in some northerly direction into Bengal or in some westerly direction across Orissa. The chief feature of the June cyclonic storms is the strong westerly or south-westerly winds or gales in their southern quadrants. It should also be noted that two out of three advance across the north-west angle of the Bay immediately to the south of the entrance to the Hooghly, and hence, if severe, they are very trying to shipping leaving the Hooghly at such times.

July.—During this month the two monsoon currents, the Bengal and Bombay currents, blow most steadily and strongly. Cyclonic storms are of frequent occurrence in the Bay, but are generally of feeble strength. The storm track charts of the month (Plates XXIII and XXXII) show that they almost without exception originated to the north of latitude 19° N. and marched in a west-north-west course across the Orissa Coast. The tracks of 39 storms which occurred during this month in the period 1877—99 are given in these charts. Of these, nineteen were feeble storms in which the force of wind did not exceed 8. Sixteen were moderate storms, in which winds of force 8 to 10 or 11 were experienced, and four were severe and attended with hurricane winds (force 11 to 12). A brief statement of these 39 storms is given in the following table :—

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1877	11th to 15th July .	W.	Balasore Coast . .	Feeble small cyclonic storm.
1878	20th to 30th „ .	W.N.W.	Ganjam Coast . .	Moderate cyclonic storm.
1880	14th to 17th „ .	W. & W.N.W.	Balasore Coast . .	Feeble ditto.
1881	2nd to 4th „ .	W.	Ditto . .	Ditto ditto.
1881	12th to 18th „ .	W. & W.N.W.	Bengal Coast near Saugor Island.	Moderate ditto.
1882	11th to 16th „ .	W.N.W.	Orissa Coast . .	Severe cyclonic storm.
1882	17th to 23rd „ .	N.W.	Bengal Coast near Saugor Island.	Ditto ditto.

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1882	23rd to 26th July .	N.W.	Balasore Coast . .	Feeble cyclonic storm.
1882	31st July to 2nd August	W.N.W.	Orissa Coast near False Point.	Ditto ditto.
1883	3rd to 5th July .	N.N.W.	Coast of Sunderbans in Bengal.	Moderate ditto.
1883	6th to 10th " .	W.N.W.	Orissa Coast . .	Severe ditto.
1883	12th to 14th " .	W.	Ditto . .	Moderate ditto.
1883	26th to 28th " .	W.N.W.	Bengal Coast near Saugor Island.	Ditto ditto.
1884	9th to 14th " .	W.N.W. & W.	Orissa Coast . .	Ditto ditto.
1884	15th to 18th " .	W.N.W.	Ditto . .	Feeble ditto.
1884	18th to 28th " .	N.W.	Ditto . .	Ditto ditto
1885	14th to 17th " .	W.N.W.	Orissa Coast near False Point.	Ditto ditto.
1885	23rd to 25th " .	N.W.	Balasore Coast . .	Ditto ditto.
1886	16th to 23rd "	W.N.W.	Ditto . .	Ditto ditto.
1887	1st to 10th " .	N.N.W. & N.W.	Orissa Coast . .	Ditto ditto.
1887	17th to 27th " .	N.N.W. & N.W.	Ditto .	Moderate ditto.
1888	11th to 15th July .	W. by N.	Orissa Coast between Puri and Gopalpur.	Feeble ditto.
1888	18th to 23rd " .	W.N.W.	Bengal Coast to east of Saugor Island.	Ditto ditto.
1889	13th to 22nd " .	N.W.	Orissa Coast between Saugor Island and Balasore.	Moderate ditto.
1889	27th to 30th " .	W. by N.	North Orissa Coast near Balasore.	Feeble ditto.
1890	29th June to 5th July .	W.N.W.	Orissa Coast near Puri	Moderate ditto.
1890	18th to 24th July .	N.W.	Bengal Coast between Balasore and Saugor Island.	Feeble ditto.
1891	24th to 30th " .	Formed at mouth of Hooghly.	Bengal Coast near Saugor Island.	Moderate ditto.

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1892	7th to 13th July .	N.N.W. and W.N.W.	North Orissa Coast near Balasore.	Moderate cyclonic storm.
1893	29th July to 5th August.	N.W.	Orissa Coast near Balasore.	Feeble ditto.
1894	10th to 14th July .	W.N.W.	Orissa Coast near Puri	Moderate ditto.
1894	14th to 24th „ .	N.W.	Orissa Coast near Balasore.	Ditto ditto.
1894	23rd to 28th „ .	N.W.	Bengal Coast east of Saugor Island.	Ditto ditto.
1895	17th to 21st „ .	N.N.W.	North Orissa Coast .	Feeble ditto.
1895	28th July to 2nd August.	W.N.W.	Orissa Coast near Balasore.	Ditto ditto.
1896	22nd to 27th July .	W.	Orissa Coast near Shortt's Island.	Moderate ditto.
1896	26th to 30th „ .	W.	West Bengal Coast near Saugor Island.	Severe ditto.
1897	7th to 10th „ .	W.	Orissa Coast north of False Point.	Feeble ditto.
1898	1st to 8th „ .	Formed over Sunderbans.	Bengal Coast . .	Moderate ditto.

Storms exactly similar in character to the above occasionally originate in Bengal itself, generally in East Bengal. As they form under like conditions, they march in the same general westerly direction across the head of the Peninsula. The chief feature in these land-formed storms, as in the corresponding sea-formed storms, is the strong westerly and south-westerly winds which prevail in their southern and eastern quadrants.*

The charts shew that all the 39 storms which formed in the Bay during this month in the period 1877—99 marched in west or west-north west directions across the north-west angle of the Bay and the centres of all, with about six exceptions, crossed the coast between Saugor Island and Gopalpur. In the great majority of cases they afterwards advanced across the head of the Peninsula into Sind, Gujarat or Rajputana. Out of the 34 storms which occurred during the period 1882—99 (*vide* Plate XL), winds of force 8 or upwards were actually experienced in 18 cases.

* The tracks of two of these storms are given in the storm-track chart of the month (Plate XXIII) in illustration of this fact.

Hence, so far as these facts indicate, in July storms only occur in the north of the Bay. They are of comparatively frequent occurrence, an average of two or three occurring in every year. Their centres usually march in west or north-north-west directions across the north-west angle of the Bay to the coast between Saugor Island and Gopalpur. The chances that a storm in this month will march in that direction are at least 10 to 1. They are frequently feeble, but in about one case out of two they give rise to strong westerly and south-westerly gales at the head of the Bay, in which the force of the winds exceeds 8. As they almost invariably cross the north-west angle of the Bay, and hence advance across the track of vessels leaving the Hooghly, outward bound vessels should not leave the river Hooghly when the storm signals are hoisted, unless fully prepared to encounter a severe storm of this kind, and should remain in the river until the lowering of the signals has indicated that the storm has passed landwards.

The following gives a complete list of cyclonic storms recorded in this month previous to the year 1877:—

15th July 1848.—Gale at the Sandheads.

23rd to 26th July 1858.—Slight gale at the head of the Bay.

11th to 28th July 1859.—Cyclone formed to west of the Nicobars; and travelled north-westwards.

25th to 31st July 1860.—Gale off Ceylon and the Coromandel Coast.

16th to 18th July 1871.—Gale in the Andaman Sea.

14th to 31st July 1872.—Gale over the south of the Bay.

This list includes only six storms extending over a period of nearly thirty years. It thus confirms what has been stated on more than one occasion in this book, that the true cyclonic character of the July storms was formerly not recognised, as they usually form close to the Bengal Coast, and in consequence give rise to westerly gales at the head of the Bay and the winds usually shift slightly with the westward advance of the storms, but not sufficiently to indicate their cyclonic character. Also the winds do not often rise in force beyond 9 and are very rarely of hurricane strength (12).

It may be of interest to note that the average strength of the winds in this month in the Bay is 4·1, and that they are strongest in the mid-Bay between longitude 88° and 92° east, and latitude 12° and 16° north—where they average 5·3.

August.—The south-west monsoon blows somewhat less steadily in August than in July, although the mean force of the winds is the same (*viz.* 4·1). The winds are of the greatest average force (5·4) in the area between 88° and 92° east meridians and 12° and 16° north parallels of latitude, or in the centre of the Bay. The track charts of the month (Plates XXIV and XXXI) for the period 1877–99 give the tracks of thirty-two storms. Twenty-three of these originated in or to the north of latitude 20° north. Six advanced in a general northerly

direction across the Bengal or North Orissa Coast into Central and North Bengal. The remaining twenty-six (with one remarkable exception) advanced in west or west-north-west directions across the coast of Orissa or Ganjam, and hence the great majority of these storms followed the usual track of cyclonic storms during the height of the south-west monsoon. They marched across the head of the Peninsula into Sind, Rajputana, or the western districts of the North-Western Provinces. The centres of nineteen of these storms crossed the coast to the east of Shortt's Island and of thirteen to the west. The following gives a brief list of these thirty-two storms :—

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1877	6th to 10th August .	N.	South Bengal Coast .	Feeble cyclonic storm.
1877	13th to 17th " .	N.N.W.	Ditto .	Probably moderate cyclonic storm.
1877	18th to 21st " .	N.W.	Ditto .	Feeble cyclonic storm.
1877	27th to 31st " .	W.N.W. and N.W.	Balasore Coast . .	Moderate ditto.
1878	1st to 4th " .	W.N.W.	Orissa Coast . .	Feeble ditto.
1878	6th to 8th " .	W.N.W.	Balasore Coast . .	Ditto ditto.
1879	8th to 13th " .	W. and W.N.W.	Ditto . .	Ditto ditto.
1880	18th to 25th " .	N.W.	Ditto . .	Ditto ditto.
1880	1st to 9th " .	W.N.W.	Ditto . .	Ditto ditto.
1881	1st to 4th " .	W.	Orissa Coast near False Point.	Ditto ditto.
1881	16th to 19th " .	W.N.W.	Balasore Coast .	Ditto ditto.
1882	18th to 24th " .	W.N.W.	Bengal Coast near Saugor Island.	Moderate ditto.
1883	22nd to 26th " .	W.	Ganjam Coast . .	Feeble ditto.
1884	2nd to 9th " .	N.N.W.	Balasore Coast . .	Ditto ditto.
1885	15th to 18th " .	W.N.W.	Ditto . .	Feeble ditto.
1886	12th to 21st " .	N.W. to N	Orissa Coast near Puri.	Moderate ditto.
1887	17th to 20th " .	W. and N.W.	Ganjam Coast . .	Feeble ditto.
1887	21st to 26th " .	N.N.W.	Balasore Coast . .	Ditto ditto.
1888	4th to 10th " .	W.N.W.	Orissa Coast . .	Ditto ditto.
1888	20th to 29th " .	N.	Bengal Coast near Saugor Island.	Moderate ditto.
1889	4th to 11th " .	W.	Orissa Coast near Balasore.	Ditto ditto.
1889	13th to 20th " .	N.W.	Bengal Coast near Saugor Island.	Severe ditto.

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1891	31st July to 5th August	W.N.W. and W. by N.	Orissa Coast between Balasore and False Point.	Moderate cyclonic storm.
1892	29th August to 7th September.	N.W.	South Orissa Coast .	Ditto ditto.
1895	5th to 10th August .	N.N.W.	Orissa Coast near False Point.	Ditto ditto.
1896	1st to 5th " .	N.W.	Bengal Coast near Saugor Island.	Ditto ditto.
1896	12th to 16th " .	W.N.W.	Orissa Coast near Shortt's Island.	Ditto ditto.
1896	19th to 23rd " .	N.W.	Bengal Coast east of Saugor Island.	Feeble ditto.
1897	12th to 19th " .	W.	Orissa Coast near Shortt's Island.	Moderate ditto.
1898	7th to 12th " .	N.W.	Bengal Coast to east of Saugor Island.	Ditto ditto.
1899	7th to 13th " .	W. by N.	Orissa Coast . .	Ditto ditto.
1899	26th to 31st " .	W.N.W.	Ditto . .	Feeble ditto.

The preceding data hence establish the following rule :—

Cyclonic storms are almost of as frequent occurrence in August as in July. Five out of every six form to the north of Lat. 19°. The chief feature of the storms of August, as in July, is strong westerly and south-westerly gales at the head of the Bay, and the shift of wind is rarely large enough to indicate their cyclonic character except in the north-west angle of the Bay. The storms of the month occasionally advance northwards across the Bengal Coast, but most frequently in west or west-north-west directions across the Orissa or Ganjam Coast. The chances, based on previous experience, that a storm which forms in the month will advance in a westerly or west-north-westerly direction are four to one, and that it will advance in some northerly direction into Bengal are one to four. As the great majority of these storms advance across the track of vessels leaving the Hooghly, captains of vessels about to proceed to sea from Calcutta at a time when the storm signals are hoisted, should if possible, unless they are prepared to encounter strong winds and a very heavy sea, remain in the river until the storm has advanced landwards.

The list of storms in August previous to the year 1877 recorded in the Meteorological Office is very imperfect for the reasons given for the similar deficiency in July, and is as follows :—

3rd August 1834.—Gale at Calcutta.

21st August 1844.—Cyclone at Calcutta.

9th to 17th August 1857.—Gale over the northern half of the Bay.

18th to 19th August 1857.—Gale over the centre of the Bay.

25th to 31st August 1859.—Storm formed in about latitude 7° N., longitude 90° E., and travelled northwards to latitude 12° N.

17th to 21st August 1861.—Slight gale over the head of the Bay.

9th to 12th August 1862.—Gale over the centre of the Bay.

10th to 11th August 1863.—Storm in the centre of the Bay to the westward of the Andamans.

28th to 31st August 1863.—Gale in the extreme south of the Bay.

16th to 25th August 1865.—Gale over the northern part of the Bay.

3rd to 6th August 1873.—Storm formed over the centre of the Bay and travelled north-north-west.

1st August 1874.—Cyclone crossed the north of the Bay from near Akyab and travelled west-north-westward.

This list confirms the preceding statement as to the general fact that storms are almost exclusively confined in this month to the north of the Bay. As a portion of the information is indefinite, it is not desirable to utilize it to modify the rule of probable occurence of storms in August given above.

September.—The south-west monsoon blows less strongly and steadily over the Bay than in the preceding three months. It usually retreats from the greater part of Upper India (including the Punjab, Rajputana, Central India and the North-West Provinces) during the third or fourth week of the month. Hence it does not extend, on the average, so far northwards as in the preceding months of July and August. A reference to the storm track charts of the month (Plates XXV and XXXII) will show a similar feature in the storms of the month. They form further south in the Bay, and when they advance in a westerly track they frequently cross the coast further to the south than storms usually do in July or August. The storm track charts of the month for the period 1877—99 give the tracks of forty-three storms, or an average of very nearly two for each year. Six formed to the south of latitude 16° north, of which three were generated to the north-west of the Andamans and two advanced across the Malayan Peninsula from the Gulf of Siam. The remaining 37 originated to the north of latitude 16° and of these the majority (twenty-two in number) formed to the south of latitude 20°. Nine of the forty-three storms advanced in a general northerly direction into Bengal or Bihar. The remaining thirty-four crossed the coast between Saugor Island and Masulipatam, and advanced in a general westerly direction across the north of the Peninsula. Their directions show greater irregularity than those of the storms of July and August, although they are as persistent and longlived. A number of these storms recurved largely after they reached land but only four recurved to a considerable extent at sea (*viz.*, the storms of 28th September to 3rd October 1886, 21st to 26th September 1887, 19th September to 3rd October 1891 and 28th September to 2nd October 1895).

The following is a brief statement of the storms whose tracks are given in the chart:—

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1877	5th to 11th September.	W.N.W. and N.W.	Balasore Coast .	Moderate cyclonic storm.
1878	13th to 21st „	W. and W.N.W.	Orissa Coast near False Point.	Feeble ditto.
1878	18th to 24th „	N. and N.N.W.	Coast of Sunderbans .	Moderate ditto.
1879	12th to 17th „	W.	Orissa Coast near False Point.	Feeble ditto.
1879	21st to 28th „	W. and W.N.W.	Orissa Coast near Puri.	Ditto ditto.
1880	12th to 19th „	W. and W.N.W.	Ganjam Coast.	Moderate ditto.
1880	21st to 26th „	W.N.W.	Balasore Coast.	Feeble ditto.
1881	10th to 14th „	W.N.W.	Orissa Coast near False Point.	Ditto ditto.
1882	6th to 15th „	W. and W.N.W.	South Orissa Coast.	Very severe cyclonic storm.
1882	13th to 16th „	W.N.W. and N.W.	Orissa Coast near False Point.	Moderate ditto.
1882	26th September to 3rd October	N.W.	Ditto.	Ditto ditto.
1884	7th to 11th September.	W. and W.N.W.	Ditto.	Feeble ditto.
1884	16th September to 1st October.	W. and W.N.W.	Ganjam Coast.	Probably moderate cyclonic storm.
1885	15th to 17th September.	W.	Balasore Coast.	Feeble cyclonic storm.
1885	19th to 25th „	N.W.	Orissa Coast at False Point.	Intense cyclone.
1886	18th to 24th „	W.N.W.	Balasore Coast.	Feeble cyclonic storm.
1886	28th September to 3rd October.	N.W. to W.	Circars Coast.	Ditto ditto.
1887	9th to 14th September.	W.	Orissa Coast.	Ditto ditto.
1887	21st to 26th „	N. and N.N.E.	Coast of Sunderbans.	Severe ditto.
1888	2nd to 11th „	N.W.	Orissa Coast near False Point.	Feeble ditto.
1888	13th to 20th „	W.N.W.	Orissa Coast at False Point.	Severe ditto.
1889	16th to 22nd „	W.N.W.	Ganjam Coast near Gopalpur.	Moderate ditto.
1890	22nd to 28th „	N.N.W.	Circars Coast between Vizagapatam and Gopalpur.	Moderate ditto.
1891	5th to 10th „	W. by N.	North Orissa Coast near Balasore.	Feeble ditto.
1891	11th to 16th „	W.N.W.	Orissa Coast near False Point.	Ditto. ditto.
1891	17th to 19th „	W.N.W.	Ganjam coast near Gopalpur.	Ditto ditto.

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1891	19th September to 3rd October.	W.W.N.W. and N.W.	Orissa Coast south of False Point.	Moderate cyclonic storm.
1892	7th to 12th September.	W.N.W.	Orissa Coast near Puri.	Ditto ditto.
1892	19th to 23rd „	W.N.W.	Circars Coast near Cocanada.	Extensive, but feeble depression.
1893	1st to 5th „	N.W. and W.N.W.	North Orissa, south of Balasore.	Moderate cyclonic storm.
1893	9th to 19th „	N.W.	Bengal Coast between Balasore and Saugor Island.	Considerable cyclonic storm.
1893	21st to 26th „	N.N.W. and N.W.	Orissa Coast between False Point and Puri.	Ditto ditto.
1894	23rd September to 1st October.	W.N.W.	Orissa Coast near Puri.	Moderate ditto.
1895	3rd to 7th September .	W.	Circars Coast near Cocanada.	Severe ditto.
1895	17th to 20th „	N.W.	North Orissa Coast.	Moderate ditto.
1895	28th September to 2nd October.	N. and N.N.E.	Bengal Coast to east of Saugor Island.	Severe cyclone.
1896	12th to 19th September.	W.N.W.	Bengal coast, west of Saugor Island.	Moderate cyclonic storm.
1897	7th to 12th „	W.	Ganjam Coast near Gopalpur.	Feeble cyclonic storm.
1897	23rd to 27th „	W.N.W.	Circars Coast between Vizagapatam and Gopalpur.	Ditto ditto.
1898	11th to 16th „	N.	Orissa coast.	Considerable ditto.
1898	19th to 21st „	N.W.	North Orissa Coast.	Feeble ditto.
1899	8th to 16th „	W.	Circars Coast between Gopalpur and Vizagapatam.	Ditto ditto.
1899	19th to 25th „	N.	Bengal Coast near Saugor Island.	Moderate ditto.

As might be expected from the general similarity of the weather conditions in the Bay and Indian area in September with those prevailing in July and August, the list of recorded cyclones or cyclonic storms previous to 1877 is as brief as the corresponding lists for July and August. The following comprises all the known storms of September, previous to 1877 :—

5th and 6th September 1808.—Cyclone at Vizagapatam.

19th to 21st September 1839.—Cyclone passed northwards across Sunderbans between Calcutta and Barisal.

21st September 1846.—Gale at Calcutta.

30th September 1867.—Cyclone at Vizagapatam.

11th September 1872.—Small cyclone in north east of the Bay.

19th and 20th September 1872.—Small storm in the north of the Bay.

This list includes six storms, of which two passed across the Bengal Coast and two across the coast of the Circars. The paths of the remaining two are not stated. Three of these storms are described as cyclones, and two of these three occurred during the last fortnight of the month.

The following gives a summary of these facts :—

Cyclonic storms are as frequent in the Bay during September as in July and August, an average of two occurring every year. These cyclonic storms however, as a rule, form further south than in the previous two months, but usually to the north of latitude 17°N. The chances are four to one that the centre of a storm which forms in September will advance in a westerly direction to the north-west coast of the Bay between Balasore and Cocanada. About one storm out of five advances in a northerly direction into Bengal. The great majority of these storms are of small intensity and resemble the storms of July and August in general character, and in the strength of the westerly and south-westerly winds in the south and east quadrants (as compared with the north-easterly and northerly winds in the north and west quadrants). Under exceptional conditions, the chief of which appears to be the earlier retreat of the south-west monsoon than usual from Northern India, these storms occasionally are of great intensity and violence, and accompanied with hurricane winds. Hence cyclones are of occasional occurrence in September (and are most probable in the last fortnight). They form in the centre of the Bay, and the chances are about even that when such a storm has formed in the Bay in September, it will advance in a north-west direction to the West Bengal or Orissa Coast or in a westerly direction to the coast of the Circars.

October.—The south-west monsoon begins to retreat down the Bay in this month. It also, in normal years, during the second or third week of the month, recurves in the centre of the Bay through south, south-east and east, and arrives on the Coromandel Coast as a north-east current giving north-east winds and frequent showers to the Coromandel Coast districts. The reversion of the south-west monsoon current, and the consequent commencement of heavy rain with strong north-east winds in Madras, are usually regarded as the setting in of the north-east monsoon on the Coromandel Coast. Hence, after this change occurs, north-east winds prevail more or less generally in the north and west of the Bay, and south-west winds in the south of the Bay. Between these areas there is an intermediate belt in which the winds are more or less variable and unsteady. In the district of predominant north-east winds the average wind force is 2·1, in the area of variable winds it is 2·8, and in the area of south-west winds it is 3·0. It will thus be seen that the conditions in the Bay during the month are very different from those of the preceding three months, and that the pre-

vailing wind directions shew a general tendency towards cyclonic motion about an area in the centre of the Bay to the west of the Andamans.

In consequence of this disposition of winds there is a marked tendency for cyclonic storms to form in the centre of the Bay furthest from land. There is hence a strong tendency for storms which form at this time to increase and become dangerous and extensive cyclones before they reach land. The storm track charts of the month (Plates XXVI and XXXIII) illustrate the effect of the change of the weather conditions from September to October on the storm tracks in the most complete manner. The tracks of thirty storms which occurred during the month in the period 1877—99 are given. They originated in every part of the Bay south of lat. 20°N. and their paths were as varied as their place of formation. Twelve marched in a general northerly direction to the coasts of Bengal and Orissa, the centres crossing the coast between Gopalpur and Chittagong. Nine advanced in westerly to north-westerly directions from the centre of the Bay to the coast of the Circars between Gopalpur and Masulipatam. Of the remaining nine eight marched from the south-west of the Bay to the Coromandel Coast, the centres crossing the Madras Coast south of Masulipatam and one advanced north-eastwards to the Arakan Coast.

The following gives the chief facts of these thirty storms :—

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1878	13th to 16th October.	N.N.W.	Coast of Circars.	Moderate cyclonic storm.
1878	28th to 31st „	W.N.W.	Ditto.	Ditto ditto.
1879	10th to 15th „	W.N.W. and N.W.	Balasore Coast.	Ditto ditto.
1879	25th to 27th „	N.N.W and N.	Bengal Coast near Chittagong.	Feeble ditto.
1880	12th to 15th „	W. and W.N.W.	Coast of Circars near Vizagapatam.	Moderate ditto.
1881	2nd to 9th „	N.W.	Coast of Circars, north of Vizagapatam.	Ditto ditto.
1882	12th to 18th „	N. and N.N.E.	Orissa Coast.	Severe ditto.
1882	26th October to 2nd November.	N.W.	Coast of Circars, east of Cocanada.	Moderate ditto.
1884	15th to 18th October.	W.	Coromandel Coast near Negapatam.	Severe ditto.
1884	24th to 26th „	N. and N.E.	Bengal Coast.	Ditto ditto.
1884	29th October to 2nd November.	N. and N.N.E.	Coast near Saugor Island and Chittagong.	Intense ditto.
1886	16th to 20th October.	W. and W.N.W.	Coast of Circars, north of Cocanada.	Small cyclone.

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1887	8th to 14th October.	W. and W.N.W.	Coromandel Coast near Madras.	Moderate cyclonic storm.
1888	1st to 9th „	N.W. and N.E.	Bengal Coast to west of Saugor Island.	Feeble ditto.
1888	27th October to 1st November.	W.N.W.	Coromandel Coast at Madras.	Severe cyclone.
1889	13th to 22nd October.	W.N.W.	Coromandel Coast near Nellore.	Moderate cyclonic storm.
1889	22nd to 27th „	N.N.E. and N.	Bengal Coast, east of Saugor Island.	Ditto ditto.
1890	10th to 14th „	N. and N.N.E.	Orissa Coast near Puri	Feeble ditto.
1890	20th to 24th „	N.	Bengal Coast, west of Barisal.	Ditto ditto.
1892	13th to 17th „	N.W. and W.	Coromandel Coast near Nellore.	Considerable cyclonic storm.
1892	18th to 21st „	W. by N.	Circars Coast between Cocanada and Masulipatam.	Ditto ditto.
1892	25th to 31st „	N.W. and W.N.W.	Coromandel Coast near Nellore.	Feeble ditto.
1893	19th to 22nd „	N.W. thro' N. to N.N.E.	Bengal Coast near Noakhali.	Intense cyclone.
1893	24th to 28th „	W. thro' N. to N.N.E.	South Arakan Coast near Sandoway.	Considerable cyclonic storm.
1894	2nd to 6th „	N.W.	Orissa Coast near Balasore.	Moderate ditto.
1894	27th October to 5th November.	W.N.W.	Circars Coast near Cocanada.	Ditto ditto.
1897	2nd to 6th October.	N.	Ganjam Coast near Gopalpur.	Ditto ditto.
1897	21st to 24th „	W.N.W. thro' N. to N.N.E.	Bengal Coast near Chittagong.	Very severe cyclone.
1898	9th to 15th „	W.N.W.	Coromandel Coast, south of Masulipatam.	Considerable cyclonic storm.
1899	12th to 16th „	N. to N.N.E.	Bengal Coast.	Moderate ditto.

It will thus be seen that the distribution of storms in the month of October is very irregular, and it is for this reason, as well as on account of the occasional great intensity of the storms, that October is on the whole the most dangerous and treacherous month of the year in the Bay.

The following gives a list of all the recorded cyclones and cyclonic storms previous to 1877:—

7th October 1737.—A violent earthquake and furious hurricane occurred at the mouth of the Ganges.

2nd October 1747.—Hurricane in Madras roads; storm not felt at Pondicherry.

31st October 1752.—Violent hurricane on the Madras Coast; rain fell continuously for several days.

21st October 1763.—Severe gale at Madras; all vessels in the roads lost.

29th October 1768.—Severe gale at Madras; not felt at Pondicherry.

20th October 1782.—Gale at Madras.

26th to 27th October 1792.—Gale at Madras.

19th October 1800.—Furious hurricane at Ongole and Masulipatam.

28th October 1800.—Hurricane at Coringa and Masulipatam.

23rd to 24th October 1818.—Cyclone at Madras; centre passed over town.

31st October 1831.—Cyclone at Balasore and Cuttack.

30th October 1836.—Cyclone at Madras; centre passed over town.

19th October 1838.—Gale at Kedjiri near the mouth of the Hooghly.

2nd to 5th October 1842.—Cyclone passed across the north of Bay in a north-west direction, striking the coast near False Point.

22nd October 1842.—Cyclone started from the Andamans, passing westward to Pondicherry.

12th to 14th October 1848.—Cyclone generated in the north of the Bay, and travelled north-westward to False Point.

20th to 23rd October 1851.—Cyclone formed over the north of Bay. The centre passed over the False Point light-house.

6th October 1854.—Hurricane to the south-east of Ceylon.

2nd to 5th October 1864.—Tremendous cyclone; travelled from north-west of the Andamans to Bengal.

25th October 1864.—Cyclone in the north of the Bay; passed over Vizagapatam.

27th October 1867.—Cyclone travelled from the Nicobars to Bengal; passed over Port Canning.

7th to 8th October 1869.—Storm travelled from the north-east of the Bay to the mouth of the Hooghly.

24th to 26th October 1872.—Cyclone in the Andaman Sea; passed over Narcondam Island.

13th to 16th October 1874.—Cyclone of great violence, originated in

latitude 16°N., longitude 89°E., passed north-westwards to the mouth of the Hooghly and over Midnapore.

24th to 26th October 1874.—Cyclone passed over Cocanada.

5th October 1876—Severe cyclone formed to the west of the Andamans, and travelled west-north-west to Vizagapatam.

29th October 1876.—Cyclone of exceptional violence formed near the Andamans, which travelled by a curved track to the mouth of the Megna, where the storm wave drowned 100,000 people.

This list includes 27 storms. Eleven marched in a northerly direction to the Bengal and Orissa Coasts, five to the coast of the Circars, and ten to the Madras or Coromandel Coast. One only formed in the Andaman Sea, *viz.*, the storm which marched over the Island of Narcondam. All these storms with perhaps the exception of two or three of those which crossed the Madras Coast, were cyclones, and several were of very great extent and of exceptional severity and intensity.

The following is a summary of the above facts:—

Cyclonic storms occur slightly less frequently in the Bay in October than during any of the four preceding months (an average of about one yearly). They are of rare occurrence in the Andaman Sea, and rarely, if ever, form to the north of lat. 20° N. in the Bay of Bengal. They may originate in any other part of the Bay, but form most frequently in the centre of the Bay between the Andamans and the coast of the Circars and the North Coromandel Coast. If a storm forms in this month, the chances are probably about one to two that it will develop into a severe cyclone. The chances are about even that a storm generated in this month will advance westwards to the coast of the Circars, and if it does so, the chances are also about even that it is a feeble or a severe storm, or in other words a cyclonic storm or a cyclone. The chances are about one to three that if a storm forms in this month it will advance northwards to Bengal or Orissa, and if it does, the chances that it will be a severe cyclonic storm or a cyclone are at least two to one. The chances that if a storm forms it will advance to the Madras Coast south of Gopalpur are also about one to two, but if it does, the chances that it will be a severe storm are probably about even.

November.—The general conditions in the Bay during this month are on the whole similar to those of the preceding month. The south-west monsoon winds retreat and cover a smaller area in the south and centre of the Bay than in October. The monsoon current recurves as in October, and continues to advance as a current giving north-east damp winds and much rain to the Coromandel coast districts. North-east winds extend over the whole of the north of the Bay and are of average force 3·4, while the mean strength of the

south-west winds in the south of the Bay is barely 3·0. The average strength of the winds in the intermediate belt of variable winds is practically the same as that of the south-west winds. Hence the conditions of the month indicate that storms will occur similar in character to those of the month of October but that they will probably form less frequently, and on the average further to the south, than in the preceding month.

A reference to the storm track chart of the month (Plate XXXIV) will show that these inferences are fully borne out by facts. The following gives a list and brief statement of the twenty storms ot the month which occurred during the period 1877—1899 :—

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1877	2nd to 5th November.	N.N.E. and N.	Arakan Coast.	Small cyclonic storm.
1878	3rd to 6th ,,	N.N.W. and N.W.	Coast of Circars.	Moderate ditto.
1879	1st to 5th ,,	N. and N.N.W.	Coast of Lower Burma.	Severe cyclonic storm or cyclone.
1879	15th to 20th ,,	W.N.W. and N.W.	Coast between Madras and Masulipatam.	Ditto.
1880	19th to 22nd ,,	W.N.W.	Coast near Negapatam.	Small, but severe cyclone.
1881	10th to 13th ,,	N.N.W. and N.W.	Coromandel Coast near Madras.	Severe cyclonic storm or cyclone.
1882	21st to 26th ,,	W. and W.N.W.	Coromandel Coast between Negapatam and Madras.	Very severe cyclonic storm or cyclone.
1882	28th to 30th ,,	W.N.W.	Coromandel Coast near Madras.	Moderate cyclonic storm.
1883	9th to 14th ,,	N.W. to N.E.	Arakan Coast.	Small but severe cyclone.
1883	28th November to 7th December.	W.N.W. to N.E.	Chittagong Coast.	Severe cyclonic storm or cyclone.
1884	19th to 21st November.	W.N.W.	Coromandel Coast near Madras.	Moderate cyclone.
1885	2nd to 3rd ,,	W. and W.N.W.	Coast north of Madras.	Moderate cyclonic storm.
1885	17th to 23rd ,,	N.N.E. and N.E.	Chittagong Coast.	Very severe cyclonic storm or cyclone.
1886	2nd to 16th ,,	N.W. to W.	Madras Coast.	Large and severe cyclone
1886	14th to 24th ,,	N.W. to W.	Coast of Circars.	Ditto.
1889	12th to 20th ,,	N.	Ganjam Coast near Gopalpur.	Severe cyclonic storm.
1891	30th October to 7th November.	W.N.W. thro' N. to N.E.	Bengal Coast, east of Saugor Island.	Severe cyclone.
1891	19th to 24th November.	N.E.	Arakan Coast.	Cyclone of great intensity.
1893	5th to 8th ,,	W.N.W.	South Coromandel Coast near Madras.	Considerable cyclonic storm.
1898	4th to 8th ,,	W.N.W.	Coromandel Coast, south of Madras.	Severe cyclonic storm.

It will be seen that with one exception only, all these storms formed to the south of latitude 16°N., and that fourteen formed in or to the south of latitude 12° N. Three originated in the Andaman Sea, and one advanced from the Gulf of Siam across the Malayan Peninsula (the Port Blair cyclone of November 1891), but of these four three passed out into the Bay of Bengal. Five of the storms advanced to the north-east coast of the Bay between Diamond Island and Noakhali; four to the coast of the Circars or Orissa, and the remainder eleven in number (with the exception of one, which passed from the Andaman Sea into Burma) advanced to the Coromandel Coast between Nellore and Negapatam. Of the twenty storms, fifteen were cyclones or severe cyclonic storms, and the remaining five were cyclonic storms of moderate to considerable intensity.

The following gives the list of recorded storms of the month of November previous to 1877:—

November 1797.—Gale in the north of the Bay.

12th to 17th November 1839.—Cyclone passed across the Bay from the Andamans to Coringa.

21st November 1840.—Gale to the north-east of the Andamans.

28th November 1843.—Cyclone travelled from latitude 6°N., and longitude 90°E., in a north-westerly direction, but did not reach land.

9th to 14th November 1844.—Cyclone to the east of the Andamans.

29th November to 2nd December 1845.—Cyclone passed from the south of the Bay westward to Ceylon, the centre passing near Batticaloa.

17th to 19th November 1850.—Cyclone formed in the Andaman Sea, east of Port Blair, and travelled north-north-west.

17th to 21st November 1856.—Cyclone formed in the centre of the Bay and passed westwards towards Madras.

2nd November 1857.—Cyclone formed to the east of Ceylon. The centre passed over Nellore.

5th November 1864.—Cyclone passed over Masulipatam.

12th November 1867.—Cyclone in the north-east of the Bay.

November 1868.—Cyclone at Akyab.

5th November 1870.—Cyclone formed in the centre of the Bay and passed to Vizagapatam, where the wind blew with hurricane force.

3rd November 1873.—Severe cyclone was experienced by a ship in latitude 15° 30′N. and longitude 85°E.

1st November 1874.—Cyclone passed over Cocanada from east.

10th to 12th November 1874.—Cyclone originated about latitude 19°N. and longitude 84°E., and travelled northward. The centre probably crossed the coast between Puri and False Point.

Hence cyclones may form in any part of the Bay and Andaman Sea to the

south of latitude 16°N. in the month of November. About three out of four storms which originate in this month form in, or to the south of, latitude 12°N. One storm may be expected every year in this month. The chances that a storm in November will be a cyclone are about two to one. If a storm forms, the chances that it will advance to the Coromandel Coast are even. About one storm out of four that form advances to the coast of East Bengal or of Arakan. The part of the Bay which is most free from cyclonic storms in this month is the north-west angle of the Bay and the coast from Saugor Island to Vizagapatam. On the other hand, the north-east coast of the Bay is more liable to cyclones in this month than in any other month of the year.

December.—The south-west monsoon generally covers only the more southerly portion of the Bay during the early part of December, and usually withdraws from it in the third week of the month. This retreat is due to increasing weakness in the current. Hence, although in the very limited extent over which it prevails and in some other conditions it resembles the corresponding conditions of the month of May, the air motion in the south of the Bay in December is marked by great general feebleness, as compared with that of May, and hence differs entirely in the important feature of strength. Hence it is evident that storms will be of exceptional occurrence in the month of December, and that they will be confined almost entirely to the south of the Bay. The track chart of the month (Plate XXXV), it will be seen, fully confirms this inference. Only eight storms occurred in December during the twenty-three years 1877—99. They all formed in the southern half of the Bay. Five of them crossed the Coromandel Coast, one the coast of the Circars and two advanced northwards of which one broke up at sea and the other reached the East Bengal coast. Six of these storms marched in west-north-westerly or north-westerly directions, and broke up shortly after reaching land and without crossing the Peninsula.

The following gives a list and very brief description of these eight storms :—

Year.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1878	4th to 9th December.	W. and W.N.W.	Coast of Circars.	Severe cyclonic storm.
1884	12th to 19th ,,	W.N.W.	Coast near Negapatam.	Ditto.
1886	7th to 9th ,,	W.N.W.	Coromandel Coast near Madras.	Ditto.
1888	12th to 16th ,,	W.	South Indian Coast to south of Negapatam.	Small cyclonic storm of considerable intensity.
1889	15th to 20th ,,	W. by N.	South Indian coast near Negapatam.	Moderate cyclonic storm.

YEAR.	Date.	Course in Bay.	Coast crossed by centre.	Character of storm.
1889	19th to 27th December.	W.	Coromandel Coast between Masulipatam and Nellore.	Moderate cyclonic storm.
1895	9th to 12th "	N. and N. by E.	East Bengal coast near Barisal.	Severe cyclone.
1897	24th to 29th "	N. to N.E.	Filled up in Bay in Long. 86°E. and Lat. 16° to 17°N.	Severe cyclonic storm.

The distribution of the storms of the month is better shown by the list of recorded cylonic storms in the Bay previous to 1877. The list is as follows :—

4th December 1803.—Violent hurricane between Trincomalee and Madras.

10th and 11th December 1807.—Gale at Madras. Storm local; not felt to the north of Pulicat nor to south of Pondicherry.

2nd December 1830.—A gale of the most violent description at Pondicherry and Cuddalore. At Madras a slight gale was felt in the evening.

6th December 1831.—Cyclone at Pondicherry and Cuddalore, lasting only a few hours, but fearfully destructive.

10th December 1849.—Severe hurricane at Madras.

4th December 1850.—Hurricane at Madras.

10th to 12th December 1874.—Storm in the south of the Bay.

This, in addition to the eight already mentioned, gives a total of fifteen storms during the nineteenth century. At least ten of these storms were cyclones or severe cyclonic storms, that is, were accompanied with hurricane winds at and near the centre. Twelve out of these fifteen storms advanced in a west-north-west direction to the Coromandel Coast, and nearly all struck the coast between Madras and Negapatam. These statements hence indicate the following rule :—

Storms are of comparatively rare occurrence in the month of December and only two storms are known to have formed in the Bay during the present century after the 15th of the month. No storm has been known to form in the Andaman Sea in this month. Storms occasionally form in the south or south-west of the Bay of Bengal between the Ceylon Coast and the Andamans. The chances are nearly two to one, that if a storm occur in this month it will be a violent cyclone. It is also almost a certainty that a storm which forms in this month will advance in a west-north-west direction to the Coromandel Coast between Madras and Negapatam. Hence they are chiefly dangerous in the area between the East Ceylon Coast and the Coromandel Coast.

Barometric Indications.—These have already been discussed from a general standpoint in the preceding chapter. All that is now necessary is to summarize the facts and principles so far as they bear directly on the determination of the existence and character of cyclonic storms.

The movement of the barometer in the Bay of Bengal is, in ordinary weather, very regular, and is confined within narrow limits. In fine weather the most noticeable and important change is the regular up and down movement (occurring twice a day) known as the diurnal oscillation or the daily barometric tides.

When a cyclonic storm or cyclone is forming or has formed and is advancing over the Bay, it is usually merely the inner part of an extensive area of barometric depression and of cyclonic circulation.

If the storm be a small one, or what is termed a cyclonic storm, the depression or fall of the barometer below its normal height for the period is never large. It increases in amount from the outskirts of the depression to the centre of the storm, but even there it does not exceed two or three-tenths of an inch in the great majority of the smaller cyclonic storms in the Bay.

If the storm be a fierce and extensive cyclone, it consists, as has been already pointed out, of—

1st.—An outer storm area.
2nd.—An inner storm area.
3rd.—A calm central area.

In the outer storm area the barometer does not fall more than four or five-tenths below the normal height of the season. The inner storm area is one of comparatively small diameter, in which the barometer falls with excessive rapidity until the calm centre is reached. The barometer, it is believed, stands at nearly the same height over the whole central calm area at the same instant, but varies with the changes in the intensity of the storm. As it should be the object of the mariner to avoid the inner storm area, it is only necessary to give the barometric indications by which he can recognize whether he is in an area of barometric depression, and approaching or entering a cyclonic storm, or is in the outer storm area of a cyclone.

If the mariner in the Bay of Bengal is provided with a proper barometer, and makes the daily comparisons suggested and explained in pages 38 to 59, he can use the variations of the barometer from the normal as storm indications by means of the following rule :—

If the reduced barometer reading is at any time during the cyclone season, April to November, a tenth of an inch below that normal to the time, the probabilities are two to one that a cyclonic storm has formed in the Bay; if ·15″ below it, the probabilities are at least three to one; and if two-tenths of an inch below, it is practically certain that a cyclonic storm has formed.

In this manner, whilst he is quite in the outskirts of a cyclonic storm his barometer may strengthen and confirm the inference derived from the appearance of the sky and weather, the occurrence of squalls, etc., of the formation or existence of a cyclonic storm in his neighbourhood.

Another rule or principle, but one less simple in its application than the previous, is the following :—

If the barometer at or near the same place (or if proper allowance be made for change of place) falls a tenth of an inch in 24 hours in any part of the Bay, the chances are about 2 to 1 that a storm is forming in the neighbourhood of the place, or is approaching the place ; if it falls ·15″ in 24 hours, the chances are about 4 to 1 that a cyclonic storm or cyclone is forming or approaching ; and if it falls two-tenths of an inch or upwards in 24 hours, it is almost practically certain a cyclonic storm is approaching the place.

Mariners should also remember that whilst a storm is forming, the barometer is frequently unusually high and steady beyond the outskirts of the incipient cyclonic storm. The same conditions of a high and steady barometer also frequently obtain in very fine settled weather. It is partly on this account, and partly on account of the very small fall of the barometer in the outer portions of cyclonic storms in the Tropics that, as ordinarily used by sailors, that instrument frequently gives no indication to them of the approach of a storm until it is too late to be of any use.

Wind indications.—We have already in part discussed the important question of the bearing of the centre of a cyclonic storm with respect to the wind direction (pages 24 to 29). We there considered the general relations holding between baric gradients and wind direction and force. We repeat the chief points of those remarks before taking up the special question of how to utilize the measurement of wind direction to ascertain the bearing and course of the centre of a cyclonic storm.

One of the most important features of the weather is the occasional occurrence of what are called barometric depressions. These are really vast revolving eddies or whirls in the atmosphere. Just as an essential feature of an eddy in water is a difference of level at the upper surface of the water (greatest in the middle of the eddy), so in an atmospheric eddy there is at the bottom of the eddy or at the earth's surface a difference of pressure which is greatest in the middle or interior of the eddy. The pressure or height of the barometer decreases from the outskirts of the eddy towards the interior. It is perhaps difficult to grasp fully that in a large cyclonic storm a vast mass of air 200 or 300 miles in diameter and ½ mile to 2 or 3 miles in height, is whirling or circulating round in a somewhat complicated manner, which, at and near the earth's surface, has been described as spiral, or vorticose. All observations of cyclonic storms shew that such, however, is the case. Such an eddy is called a

barometric depression from one feature, *viz*, that the barometer is depressed below its natural or normal height in the eddy at the earth's surface, and that the depression increases towards the centre in a fairly regular manner. It is also called a cyclonic circulation, cyclonic storm or cyclone, from the manner in which the air moves or whirls in a regular manner round a definite point or small area in the interior of the eddy or whirl. The point in such an eddy where the barometer stands lowest, and which, so far as experience shews, generally coincides with the point or small central area about which the air circulates and towards which it is drawn, is called the centre. The shape or form of these atmospheric eddies is best shewn by the lines of equal pressure or isobars indicating and defining cyclonic storms in weather charts. They are very rarely circular, and are usually more or less oval and fairly regular in shape. They differ very largely in size, and also in the rate at which the air moves. Hence a cyclonic circulation may be either feeble, moderate or violent. If feeble, it is of little or no importance to sailors, except so far as they choose to use the winds for progress. If moderate, it may be called a "cyclonic storm," and if very violent, a cyclone or hurricane.

As suggested by Mr. Blanford, it appears to be desirable to retain the use of the word 'cyclone' for the most violent storms in the Bay of Bengal, and to employ the term 'cyclonic storm' for the less violent disturbances which are of frequent occurrence during the whole of the south-west monsoon period.

In cyclones and cyclonic storms the pressure slope or baric gradients are from the outside towards the centre, and, roughly speaking, coincide in direction with the bearing of the centre.

I have made measurements of the bearing angle, that is, the angle between the direction from which the wind comes and the bearing of the centre, for nearly every cyclone which has occurred during the past twenty-five years. Although there are considerable differences between single measurements, the average of a large number of such measurements gives an angle of almost constant value. This difference between individual measurements might be expected for a variety of reasons, of which the following are the most important:—

(*a*) Wind observations on board ship are taken on a moving body, and hence the motion of the air recorded is that with respect to the vessel, which may differ considerably from its actual direction with respect to the earth's surface. Thus, if the vessel be going 10 miles per hour and the air velocity be 60 miles per hour, the error may be as much as a point either way, and will of course be greatest if she is going at right angles to the wind. I have not been able to find in any works of reference any statement of the methods usually adopted by sailors for measuring wind directions. In ordinary weather, and with steady winds, it is probably best

served by noting the direction from which the sea (*vide* page 24) is advancing. In stormy weather, when the winds are strong and ships usually advance slowly, the apparent direction of the wind may be assumed to be the true direction. If the vessel is not advancing more than 4 or 5 knots per hour, this will not introduce any sensible error in estimating the wind direction in the outer storm area of cyclones or in cyclonic storms, but, as already stated, if going 10 miles an hour and at right angles to the wind and with a strong current aiding her progress, it might introduce an error of a point one way or the other.

(*b*) Sailors usually measure wind to 32 points of the compass. Hence when the actual direction of the wind varies less than half a point in either direction from one of these points it can only be estimated by that point. Consequently the rough method of measurement of direction employed allows a range of error not exceeding two-half points, that is, of a whole point (or $11\frac{1}{4}°$). This possible range of error is hence relatively large, and hence the measurement of wind direction on board ship is rough and inexact.

(*c*) The measurement of wind direction on board ship is ascertained by reference to the standard compass. The effect of the strong winds in causing the vessel to lie over towards one side introduces an error in the compass, usually known as 'the heeling error,' the amount of which it is difficult to ascertain, and which is rarely, if ever, allowed for in such cases. The following gives a brief general statement of the heeling error: "The heeling error is an error in the compass of an iron ship due to her heeling to starboard or port. With her head to the *northward* on the starboard tack, easterly deviation is induced; on the port tack westerly deviation is induced. Heading *south*, westerly deviation is induced on the starboard tack, and easterly deviation on the port tack." I have been unable to find any statement of the amount of deviation or error which may be thus produced, but have no doubt it may occasionally be as much as a point. A measurement of wind direction during strong cyclonic winds may hence be affected to the extent of a point by this cause.*

* I have recently received the following note from Mr. Elson, Master Pilot, Calcutta Pilot Service, on this subject :—

"In the cyclone of October 1874 the S. *Burdwan* lying at Saugor Roads (about 2 miles from Saugor Island) in her report of the storm gives wind as north-north-east whilst the Saugor observer gave it as north-east at a particular time. This discrepancy of two points was no doubt attributable to heeling error. The rule is the north point of the compass is invariably drawn to windward in the northern hemisphere so that the *Burdwan* riding at anchor with wind north-east would have a list to port on the ebb and to starboard on the flood so that, on either tide, the compass would be drawn to windward more or less to starboard on the ebb and to port on the flood. I suppose the two points difference between ship and shore station and of course all bearings taken of wind or objects would contain this error of two points right or, as termed, easterly deviation."

Hence it appears that the measurement of wind direction may be affected by errors of various kinds to a very considerable extent, probably to a limit of two points on either side, or the total range of error may be as much as four points. This, it is hardly necessary to say, is a very wide range of possible error, and it hence makes wind observations on board ships much less reliable and valuable in storms than they would otherwise be.

It will thus be seen that the measurement of wind direction, especially during storms, is liable to several large errors, and it would be hopeless in the present state of these observations to expect perfectly consistent results when comparing single observations. As, however, in a large number of observations the number and magnitude of the errors in one direction will very probably almost exactly counterbalance those in the opposite direction, the mean of a large number of such observations will probably give a satisfactory and consistent and reliable result of the bearing of the centre referred to the wind direction. This inference, it will be seen, is borne out by the following results.

The following is the summary of the results obtained for seven of the cyclones described in the following chapter. In these I have carefully selected only the most trustworthy observations of wind on board ships, the position of which and of the storm centre at the same time were known with sufficient exactness to give a trustworthy and accurate measurement of the bearing angle :—

Cyclone.	Year.	Average Bearing angle.	Remarks.
Calcutta	1864	126°	Based on 4 measurements.
Backergunge . . .	1876	118°	„ 16 „
Midnapore	1874	{ 119°	„ 18 „
		124°	„ 6 „
False Point	1885	{ 114°	„ 5 „
		109°	„ 6 „
Akyab	1884	113°	„ 8 „
Port Blair	1891	118°	„ 6 „
Chittagong	1897	111°	„ 2 „

Assigning equal weight or value to each storm these figures give an average of 117° or 10½ points almost exactly for the bearing angle.

I have made measurements for other cyclones, and the average results of these agree almost equally with the preceding.

This result may be summarized as follows :—

To determine the bearing of the centre at any position within a cyclonic

storm face the wind exactly, then the centre will be between 10 and 11 points to the right hand (or, more exactly, 10½ points).

It is very probable that there are very slight differences in the amount of the bearing angle in different quadrants of as much as half a point to a point, but I have not been able from the available data of the Bay to obtain satisfactory results or to formulate a rule that could be relied on for safe guidance.

The following table gives the direction of the storm centre corresponding with any given direction of the wind in accordance with the assumption that the bearing angle is between 10 and 11 points. It is on the average nearly midway between the two directions given in each case :—

Direction of wind.	Probable direction of centre.
N.	Between E.-S.-E. and S.-E. by E.
N.-N.-E *	„ S.-E. and S.-E. by S.
N.-E.*	„ S.-S.-E. and S. by E.
E.-N.-E.*	„ S. and S. by W.
E.	„ S.-S-W. and S.-W. by S.
E.-S.-E.	„ S.-W. and S.-W. by W.
S.-E.	„ W.-S.-W. and W. by S.
S.-S.-E.	„ W. and W. by N.
S.	„ W.-N.-W. and N.-W. by W.
S.-S.-W.	„ N-W. and N.-W. by N.
S.-W.	„ N.-N.-W. and N. by W.
W.-S.-W.	„ N. and N. by E.
W.	„ N.-N.-E. and N-E. by N.
W.-N.-W.	„ N.-E. and N.-E. by E.
N.-W.	„ E.-N.-E. and E. by N.
N.-N.-W.	„ E. and E. by S.

In connection with this general rule sailors will probably wish to know—

(1) whether it holds up to the centre or central calm area;

(2) whether it is the same in all quadrants;

(3) whether the same rule holds in the south of the Bay as in the centre and north.

All that can apparently be inferred from the evidence and information collected up to the present date on these important points is as follows :—

1st.—In the larger cyclones having a central calm area, there is no motion into the calm centre at the earth's surface, and the whole air motion just outside the central area is hence tangential to the central area. The central area is, however, in all cases for

* It should be carefully remembered that, for reasons given elsewhere, although this direction for north-east winds holds good over the greater part of the Bay, it fails occasionally in the north-west angle of the Bay. With the wind in that direction, the bearing of the storm centre may be in any direction between south-south-west and south-east.

which there is evidence forthcoming oval rather than circular in shape, and hence the bearing angle will, even in that part of the cyclone, not be eight points, but will almost certainly on the average be less than 10 points. As these large and intense cyclones are only the development of smaller cyclones, it is probable that the average bearing angle may be less than 10 to 11 points near the centre in the case of the smaller cyclonic storms, but the evidence is not sufficient to establish this with certainty. All investigation up to the present time, however, appears to show that the above general rule holds over the whole of the outer storm area, and also for some distance within the inner storm area. If the sailor be involved in the latter, it will probably be too late for him to do much to extricate himself, and rules are then of little or no use.

2nd.—There are not a large enough number of exact observations to enable a decisive answer to be given to this point. It appears to be true in the south, east and north quadrants. As already pointed out, there is a very marked tendency for the wind to hang at north-east much longer than is consistent with the above rule in the north-west angle of the Bay when a storm is advancing to the Orissa or West Bengal Coast, more especially in the large storms of September and October. The reasons for this are as follows:—

(*a*) The north-east winds of indraught in this quadrant are feeble and are identical in direction with the normal winds of the period, and hence the actual wind is not a cyclonic wind, pure and simple, but is the previously prevailing wind strengthened and slightly modified in direction by the indraught to the storm area.

(*b*) The general character and trend of the Orissa coast, and the lie of the Orissa hills are such as can give a general north-east tendency or direction to all northerly winds blowing across Orissa and the north-west angle of the Bay.

The mariner should most carefully remember the peculiarly treacherous character of the north-east winds at the head of the Bay in the cyclone months of October and November (*vide* page 128).

3rd.—The measurements that have been made indicate that the bearing angle is probably slightly greater in the south than the north of the Bay, but not to so large an extent as to affect the general rule given above.

Hence, with the one important exception noted above (*viz.*, of the north-east winds in the north-west quadrant in the case of storms advancing to the Orissa or West Bengal coast), I believe the preceding rule is exact enough for the ordinary requirements of practical men and sailors who require a fairly definite rule on the subject and have to apply it under circumstances when exact measurement is almost an impossibility. It should, of course, be remembered that there may be real exceptions due either to irregularity in the cyclonic circulation itself, or to features not yet fully recognized, and that there are apparent exceptions, due to errors in the measurement of wind direction on board ships.

As the above rule has not yet obtained general acceptance by seamen and marine authorities, it is desirable to give brief extracts from the writings of various meteorologists showing that it is in accordance with the opinions of those meteorologists in different parts of the world who have made a study of this important subject.

The first is from Mr. Blanford's *Vade Mecum*, Part II, published some years ago, chiefly for the use of Indian Meteorological observers. In this he says—

"The degree to which the winds curve inwards towards the centre, or depart from a truly tangential direction, is a point on which further evidence is desirable. Redfield was of opinion that 'it is not probable that, on an average of the different sides, it ever comes near to forty-five degrees from the tangent of a circle; and that such average inclination ever exceeds two points of the compass may well be doubted.' But Mr. Meldrum has shown that, at a considerable distance from the centre, the direction is sometimes radial or nearly so. In the case of the storms of the Bay of Bengal, the following rule given by Mr. Wilson is probably a fair generalisation:—'With the face to the wind, the direction of the centre is from ten to eleven points to the right-hand side.' It certainly varies, however, in different storms, and even at different times and in different parts of the same storm, and as the result of a comparison of the charts given by different describers, it seems to me that, on land and in the neighbourhood of land, the direction is considerably more radial or less tangential than on the open sea. I am, however, entirely of the opinion of Mr. Meldrum and Mr. W. G. Wilson, that a rigorous adherence to the rules laid down by Reid, Dove and Piddington, which proceed on the assumption that the winds blow in a tangential direction, and which disregard their spiral convergence, is dangerous in practice and

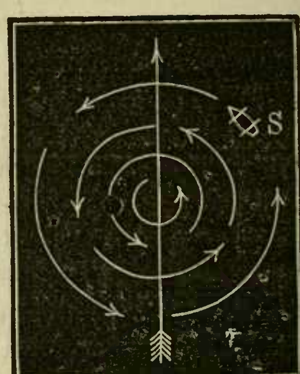


FIG. 21.

may lead to disaster. A comparison of the two adjoining figures, one of which represents the course of the winds in a cyclone, as assumed in the rules laid down by the above authors, the other that which results from Messrs. Meldrums, Wilson's, and my own experience, will facilitate a comprehension of the point at issue and its bearings. If Figure 21 were a true representation of the course the winds in a cyclone, a ship, in the position S. with a south-east wind aft, might, by keeping the wind aft, safely run across the path of the advancing storm and escape injury; but if Figure 22 be a more accurate representation, then to follow such a course would infallibly lead the vessel into the very heart of the cyclone."

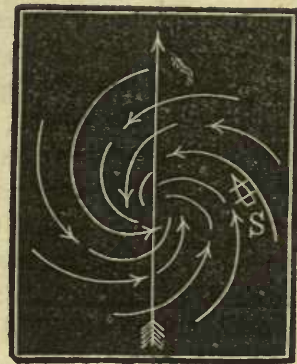


FIG. 22.

Mr. Blanford considered very carefully the question of the bearing of the centre with respect to the wind direction and gave the following results in *Nature* (Vol. XXXVIII, number of June 21, 1888) :—

"1. The mean of 132 observations between latitudes 15° and 22° within 500 miles of the storm centre, gives the angle 122° between the wind direction and its radius vector.

"2. The mean of 12 observations between the same latitudes within 50 miles of the storm centre, gives the angle 123°.

"3. The mean of 68 observations, between north latitudes 8° and 15° within 500 miles of the storm centre gives the angle 129°.

"4. The observations within 50 miles of the storm centre in the south of the Bay are too few to afford any trustworthy result."

Mr. Blanford, from those results, deduced the following practical rules for seamen's guidance :—

"1. In the north of the Bay of Bengal, standing with the back to the wind, the centre of the cyclone bears about five points on the left hand, or three points before the beam.

"2. In the south of the Bay it bears about four points on the left hand, or four points before the beam.

"3. These rules hold good for all positions within the influence of the storm up to 500 miles from the storm centre. On the north and west the influence of the storm rarely extends to anything like this distance, but it does to the east and south."

Buchan, in his *Hand-Book of Meteorology*, states—

"The relation between the wind direction and bearing of the centre of a barometric depression is what is known as Buys Ballot's 'Law of the Winds. According to this distinguished meteorologist, if a line be drawn in the direction from which the wind comes, and another from the place of observation to that of least pressure, the angle is generally from 120° to 100°. This is unquestionably the general direction of the wind in storms, but the angle is frequently as large as 135°, especially where the winds become lighter on approaching the central space of least pressure, and on rare and peculiar occasions it is less than 100°. The wind in cyclonic storms blows round the area of low barometer in a circular manner, and in a direction contrary to the motion of the hands of a watch, with, and be this particularly noted, a constant tendency to turn inwards towards the centre of least pressure. Also, the greater the force of the wind at any place, the more nearly is the direction indicated, by the principle stated above, approximated to; and where the directions show any material departure from the general law, such winds are almost invariably light, and consequently more under local influences, which tend to turn them out of their course. Hence in cyclonic storms the winds circulate round the region of least pressure; or, to state it more accurately, the whole atmospheric system appears to flow in upon the central area of low pressure in an in-moving spiral course. This peculiarity is common to all European storms I have yet examined; and it should be particularly noted that it is no mere theory or opinion, but a simple statement of what has been constantly observed."

In the preceding paragraphs a rule has been given by which the bearing of the storm centre can be ascertained approximately from the direction of the wind at any point within a cyclonic storm or cyclone (except perhaps in the immediate neighbourhood of the calm centre). It has also been pointed out that in consequence of certain local peculiarities, this rule partially fails in the north-west angle of the Bay when a severe cyclonic storm or cyclone is approaching directly towards it. The other point for the determination of which the direction of the wind is employed, is the direction of advance or track of the storm.

The wind direction at any instant furnishes approximately the bearing of the storm. The strength and frequency of the squalls (more especially when taken into consideration with the probable character of the storm as determined by the period of the year) (*vide* pages 167 to 189), the rate at which the barometer is falling, and the average force of the wind, are sufficient to enable the sailor to form a rough estimate of the distance of the centre of any cyclonic storm in the Bay of Bengal in which he may be involved. The greater his experience and the better his judgment the more accurate will his estimate be. Some indications have already been given on these points, and hence will be assumed in the following paragraphs.

When a vessel traversing any part of the Bay of Bengal, more especially in the months of April to December, meets with squally weather, and the squalls become heavier and more frequent, the captain may be certain that he is approaching a cyclonic storm. It may be feeble, but it may be (more especially if it is in the month of May, the last half of September, October, November or December) a fierce and dangerous cyclone, with an inner storm area of hurricane winds. The wind direction will at once tell him in what quadrant he is. The variations of the barometer (if he takes exact observations, and has a properly verified barometer and makes the comparisons suggested in this book, pages 52 to 59) will tell him whether pressure is below the normal, and at what rate it is falling, and hence give him exact indications as to whether he is in the outskirts of the cyclonic storm and approaching the centre rapidly or slowly, and confirm the conclusions derived from the squally weather. A reference to the storm track charts and rules, etc., given in pages 167 to 189 will also tell him the probable character and track of the storm, so far as these depend upon the season and upon the results of past experience. He will (especially if in command of a steamer) probably continue his course, allowing perhaps his knowledge of the probable position and direction of the storm, etc., to modify his course more or less according to circumstances.

If, however, he finds that his barometer continues to fall, and the squalls and wind become heavier, he may be certain he is approaching the centre, and if he does not ascertain the approximate position and path of the centre, he may, if it is a severe cyclone, be carried, or advance, into the inner storm area. Hence it then becomes necessary to determine these points as accurately as possible.

In order to do this the captain should observe the shift of wind with respect to the motion of the cyclone only. It is hence necessary that he should slow the vessel down and allow it to be at rest as nearly as is possible under the circumstances, and remain in this position until the wind shifts. The change of the wind will give him sufficient indication to determine the path or track approximately, and (more especially where combined with the inferences based on the other weather signs and data already stated) sufficiently accurately to enable him to determine the best course to adopt to avoid the inner storm area and to pass out of the whole storm area as rapidly as possible and with the least danger to his vessel.

It will be best to illustrate the method by one or two examples. Suppose that the wind is first at west-north-west, and then shifts round to west, the shift not being due to a passingsquall, but to a *permanent change in the direction of the air motion or wind.* The direction of the storm would be before the

shift of wind very nearly eleven points to the right of west-north-west, or say, north-east. The shift of wind would indicate that the direction of the centre had changed to north-north-east. Hence, if the vessel had remained at rest during this interval, the shift of wind would show that the direction of the centre had changed from north-east to north-north-east by its own motion and hence that the storm was advancing in some westerly direction to the north of the vessel. The direction could be obtained still more exactly by taking into consideration the character of the weather during the interval before which the shift of wind was observed. If the weather become more threatening and the squalls heavier, it is evident the centre is approaching the vessel, and hence the course will, in this case, be probably about west. If no marked change occurs in the weather, then the centre is probably marching directly across, or at right angles to the mean bearing of the centre, or its track is probably about west-north-west. If, on the other hand, the weather is improving and squalls are becoming lighter, then it is almost certain the centre is not only passing across in a westerly direction to the north of the vessel, but passing away from it, and hence marching in a more northerly direction or in a north-west to north-north-west direction. The following diagram (Fig. 23) illustrates roughly these remarks:—

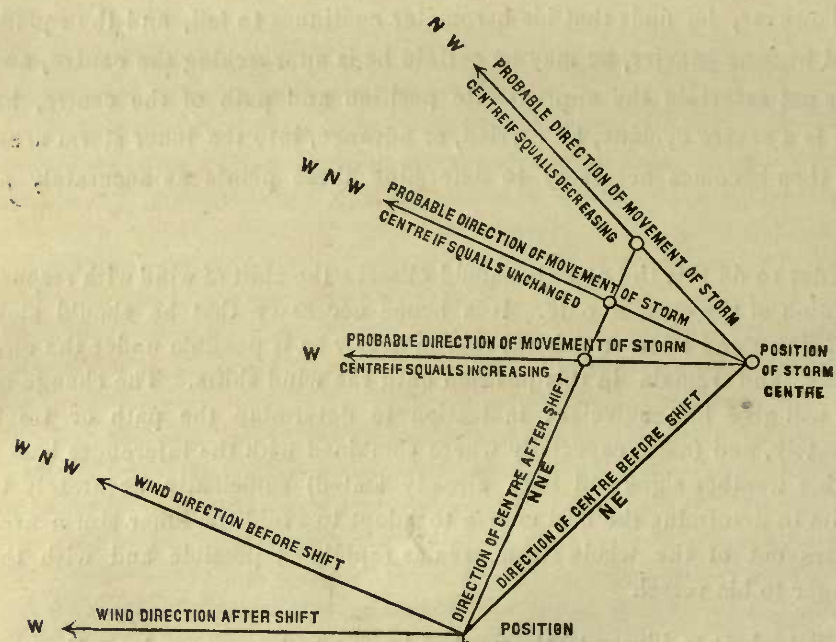


FIG. 23.

If, on the other hand, the wind shifted from west-north-west to north-west or veered instead of backing to west, as it was assumed to do in the previous case, the direction of the storm centre before the shift of wind would be north-east to north-east by east, and after the shift of wind it would be east-north-east to east by north.

The direction of motion would be hence in some easterly direction across to the north of the vessel. If the weather got rapidly worse (much more than might be expected during the approach towards the centre in the south-west quadrant of the storm), then the storm centre is almost certainly also approaching the vessel and therefore probably advancing in a southerly to south-south-easterly direction of the vessel. If the weather is practically unchanged, then it is advancing in a south-south-east direction, and if improving, in a south-east or east-south-east direction.

The following table will enable any one to determine from the wind, and shift of wind, the approximate direction of motion or track of the centre of a cyclonic storm (that is, the direction towards which it is advancing) in the three possible cases:—

(1) When the squalls are decreasing in strength.

(2) When they are unchanged in character and frequency.

(3) When they are increasing in frequency and intensity.

The table explains itself—

Direction of wind before shift.	Bearing of centre between	Wind shifts to	Track of centre (moving to): If squalls are decreasing in force and frequency.	If squalls unchanged.	If squalls increasing in force and frequency.
N. . .	E. S. E. & S. E. by E.	N. N. W.	N. N. E.	N.	N. N. W.
		N. N. E	S. S. W.	S. W.	W. S. W.
N. N. E. .	S. E. & S. E. by S.	N.	N. E.	N. N. E.	N.
		N. E.	S. W.	W. S. W.	W.
N E. . .	S. S. E. & S. by E.	N. N. E.	E. N. E.	N. E.	N. N. E.
		E. N. E.	W. S. W.	W.	W. N. W.
E. N. E. .	S. & S. by W.	N. E.	E.	E. N. E.	N. E.
		E.	W.	W. N. W.	N. W.
E. . .	S. S. W. & S. W. by S.	E. N. E.	E. S. E.	E.	E. N. E.
		E. S. E,	W. N. W.	N. W.	N. N. W.

Direction of wind before shift.	Bearing of centre between	Wind shifts to	Track of centre (moving to)		
			If squalls are decreasing in force and frequency.	If squalls unchanged.	If squalls increasing in force and frequency.
E. S. E. .	S. W. & S. W. by W.	E.	S. E.	E. S. E.	E.
		S. E.	N. W.	N. N. W.	N.
S. E. . .	W. S. W. & W. by S.	E. S. E.	S. S. E.	S. E.	E. S. E.
		S. S. E.	N. N. W.	N.	N. N. E.
S. S. E. .	W. & W. by N.	S. E.	S.	S. S. E.	S. E.
		S.	N.	N. N. E.	N. E.
S. . .	W. N. W. & N. W. by W.	S. S. E.	S. S. W.	S.	S. S. E.
		S. S. W.	N. N. E.	N. E.	E. N. E.
S. S. W. .	N. W. & N. W. by N.	S.	S. W.	S. S. W.	S.
		S. W.	N. E.	E. N. E.	E.
S. W. . .	N. N. W. & N. by W.	S. S. W.	W. S. W.	S. W.	S. S. W.
		W. S. W.	E. N. E.	E.	E. S. E.
W. S. W. .	N. & N. by E.	S. W.	W.	W. S. W.	S. W.
		W.	E.	E. S. E.	S. E.
W. . .	N. N. E. & N. E. by N.	W. S. W.	W. N. W.	W.	W. S. W.
		W. N. W.	E. S. E.	S. E.	S. S. E.
W. N. W. .	N. E. & N. E. by E.	W.	N. W.	W. N. W.	W.
		N. W.	S. E.	S. S. E.	S.
N. W. . .	E. N. E. & E. by N.	W. N. W.	N. N. W.	N. W.	W. N. W.
		N. N. W.	S. S. E.	S.	S. S. W.
N. N. W. .	E. & E by S.	N. W.	N.	N. N. W.	N. W.
		N.	S.	S. S. W.	S. W.

It may be noted that a portion of this table does not apply practically to the Bay of Bengal, as storms only advance in directions between west and north-east. Hence some of the changes of winds given in the table will not be observed in the Bay of Bengal. It appears, however, to be desirable to give the table in its most complete form.

It should also be noted that the directions of the wind in this table are given to sixteen points and that the probable tracks given are only approximate. It would be easy to give a table for 32 points, but it is thought better to test this table by experience before extending it and giving it the appearance of greater precision than it is at present entitled to. Any one who understands the principle upon which it is constructed can of course draw up a table for 32 points. It is advisable that every one using the table in a storm should employ the principles on which it is drawn up and work out the track, modifying the result by any special considerations which his experience may have suggested to him, more especially by any important weather indications not taken into account in drawing up the table.

This table is drawn up and the previous rules have been given on the supposition that the storm advances approximately in a straight course over the Bay. A reference to the charts will show that this supposition holds good in the great majority of cases. The storm track charts (Plates XXI to XXVI and XXVIII to XXXV) give the tracks of 210 storms. Of these only thirteen recurved to any considerable extent in the Bay of Bengal. The most remarkable examples were—

Storm of 9th to 14th November 1883, which recurved from north-west through north to north-east.

Storm of 28th November to 7th December 1883, which recurved from west-north-west through north to north-east.

Storm of 13th to 17th May 1884, which recurved through north to north-east.

Storm of 24th to 26th October 1884, which recurved from north through north-north-east to north-east.

Storm of 30th October to 7th November 1891, which recurved from west-north-west through north to north-east.

Storm of 19th to 22nd October 1893, which recurved from north-west through north to north-north-east.

Storm of 24th to 28th October 1893, which recurved from west through north to north-north-east.

Storm of 5th to 8th May 1898, which recurved from north-west through north to north-east.

The storm of 2nd to 16th November 1886 which crossed the Peninsula and passed out into the Arabian Sea recurved there from west-north-west through north-west and north-north-west to north and north-north-east.

Other examples might be given from earlier storms. One of the most noteworthy was the great Backergunge cyclone of October 1876, which recurved from north through north-north-east to north-east.

The data given above show that out of 210 storms in the Bay of Bengal

thirteen recurved, or about one out of every 16. Hence the recurvature of storms is an exceptional occurrence in the Bay of Bengal (probably much more so than in the Arabian Sea), and the problem of determining the path of a storm is hence in the great majority of cases in the Bay comparatively simple. Also, if a storm recurves in the Bay, all previous experience shows that it will almost certainly recurve towards the east, and generally from north-west, north-north-west or north through north-north-east to north-east. If it recurves very slowly and fairly regularly over a considerable portion of its course, it will not affect to any appreciable extent the determination of the position of the centre and the direction of its advance at that instant, so that the same rules apply as in the ordinary cases. When a storm recurves, its rate of advance is always more or less diminished, and if the recurvature be rapid, its advance is usually very considerably diminished, and the storm may remain almost stationary for some hours. Hence there will be, during such an interval, very little or no shift of wind, and the chief indication of recurvature is hence the tendency for the winds to hang much longer in one direction than is usual in ordinary storms of the period. In such a case if the vessel be moving slowly or lying-to, there will probably be little change in the height of the barometer or strength of the squalls, in this respect differing from the indications of a cyclone approaching directly towards the observer, when also there is little or no shift of wind. It is not possible to give general exact rules to the sailor for his guidance in this matter. He should recognize the possibility that any storm he may meet with in the Bay, more especially in the months of May, September, October and November may recurve considerbly to east. It is for example possible that a vessel leaving the Hooghly, when a cyclone is passing northwards up the Bay, might by steaming to south-east advance straight towards the centre of the storm if it began to recurve to north-east. Whereas, if she remained in the river until the storm was approaching the coast, and its course at the head of the Bay was known with certainty, she might in such a case take advantage of the winds in the western quadrant and run quickly down the Bay.

To sum up, storms occasionally recurve in the Bay. In such cases they always recurve towards east, the usual change being from north-north-west or north to north-east. About one storm in 16 recurves, and as about 8 storms occur on an average every year, an average of one storm in two years recurves. It is not possible, with the present knowledge, to give simple rules by which a sailor may determine from his wind observations (unless he lies-to much longer than would be desirable or probably even possible) whether a distant and approaching storm is recurving or not. It should, however, be remembered that when storms are recurving their rate of motion decreases, the shift of wind takes place very slowly, and little or no change occurs in the character of the squalls or weather to a stationary observer.

Rate of advance of cyclones.—The rate of motion of cyclones varies very greatly, not only in different storms, but also at different periods in the same storm. In the earlier stages, cyclonic storms in the Bay usually advance slowly and increase their rate of motion for some time and until they are fully formed. Also, when approaching the coast they not only occasionally increase in intensity, but also move more and more rapidly. The Backergunge cyclone, for example, which marched at an average rate of about 10 miles up the north of the Bay, increased its velocity to 20 to 25 miles per hour during the last eight or twelve hours when approaching the mouth of the Megna.

The following gives data for some of the more important storms :—

Storm.	Data of rate of motion up the Bay.	
Calcutta cyclone of October 1864.	Average rate of motion—	
	From noon of 2nd to noon of 3rd . .	. 9 miles per hour.
	„ noon of 3rd to noon 4th . .	. 9 „ „ „
	„ noon of 4th to midnight of 4th .	. 10 „ „ „
	„ midnight of 4th to 10 A.M. of 5th .	. 10 „ „ „
	„ 10 A.M. of 5th to noon of 5th .	. 18 „ „ „
	„ noon of 5th to 5 P.M. of 5th . .	. 15 „ „ „
Burdwan and Midnapore cyclone of October 1874.	The average rate of motion from forenoon of the 13th until the evening of the 15th was $6\frac{1}{2}$ miles per hour. The velocity increased to about 10 miles per hour as it approached the Bengal Coast.	
Backergunge cyclone of October 1876.	From noon of 27th to noon of 30th the average motion 4 miles per hour :—	
	From noon of 30th to 7-30 A.M. of 31st .	. 9 miles per hour.
	„ 7-30 A.M. of 31st to 1 P.M. of 31st .	. 12 „ „ „
	„ 1 P.M. of 31st to 4 P.M. of 31st .	. 13 „ „ „
	„ 4 P.M. of 31st to 6 P.M. of 31st .	. 15 „ „ „
	„ 6 P.M. of 31st to 8 P.M. of 31st .	. 18 „ „ „
	„ 8 P.M of 31st to 4 A.M. of 1st .	. 22 „ „ „
Madras cyclone of May 1877.	Average rate of motion—	
	From noon of 15th to noon of 16th .	. 3 miles per hour.
	„ noon of 16th to noon of 17th .	. 3 „ „ „
	„ noon of 17th to noon of 18th .	. $6\frac{1}{2}$ „ „ „
Akyab cyclone of May 1884.	Average rate of motion—	
	From noon of 14th to noon of 15th .	. 6 miles per hour.
	„ noon of 15th to noon of 16th .	. 8 „ „ „
	„ noon of 16th to 2 A.M. of 17th .	. 9 „ „ „
	„ 2 A.M. of 17th to noon of 17th .	. $10\frac{1}{2}$ „ „ „
	„ noon of 17th to 9 P.M. of 17th .	. 15 „ „ „
False Point cyclone of September 1885.	Average rate of motion—	
	From noon of 19th to noon of 20th .	. $3\frac{1}{2}$ miles per hour.
	„ noon of 20th to noon of 21st .	. 8 „ „ „
	„ noon of 21st to noon of 22nd .	. 14 „ „ „

Storm.	Data of rate of motion up the Bay.	
Balasore cyclone of May 1887.	Average rate of motion—	
	From noon of 21st to noon of 22nd	2 miles per hour.
	" noon of 22nd to noon of 23rd	2 " " "
	" noon of 23rd to noon of 24th	4½ " " "
	" noon of 24th to noon of 25th	6 " " "
	" noon of 25th to 4-30 A.M. of 26th	8½ " " "
Madras cyclone of October 1888.	Average rate of motion—	
	From noon of 29th to noon of 30th	7 miles per hour.
	" noon of 30th to 8 A.M. of 31st	10¼ " " "
	" 8 A.M. of 31st to noon of 31st	10½ " " "
	" noon of 31st to 9-30 P.M. of 31st	11 " " "
Port Blair cyclone of November 1891.	Average rate of motion—	
	From 8 A.M. of 1st to 2-30 A.M. of 2nd	17·8 miles per hour.
	" 2-30 A.M. of 2nd to 8 A.M. of 2nd	20·9 " " "
	" 8 A.M. of 2nd to 8 A.M. of 3rd	11·5 " " "
	" 8 A.M. of 3rd to 8 A.M. of 4th	9·2 " " "
	" 8 A.M. of 4th to 4 A.M. of 5th	10·4 " " "
	" 4 A.M. of 5th to 8 A.M. of 5th	8·8 " " "
	" 8 A.M. of 5th to 4-20 P.M. of 5th	7·8 " " "
	" 4-20 P.M. of 5th to 9 P.M. of 5th	6·9 " " "
	" 9 P.M. of 5th to 2 A.M. of 6th	9·6 " " "
	" 2 A.M. of 6th to 8 A.M. of 6th	11·6 " " "
Chittagong cyclone of October 1897.	Average rate of motion—	
	From 8 A.M. of 21st to 8 A.M. of 22nd	11½ miles per hour.
	" 8 A.M. of 22nd to 8 A.M. of 23rd	7 " " "
	" 8 A.M. of 23rd to 8 A.M. of 24th	6 " " "

The preceding table shows that the rate of motion of cyclonic storms differs very considerably even for storms of the same class, and also for the same storm at different periods of its existence. In the earlier stages of cyclones and cyclonic storms in the Bay, the velocity is generally less than 4 miles per hour. After they have fully formed, they advance in some cases with a velocity, which is uniform during the remainder of their progress at sea; but, in other cases, with a velocity which increases rapidly as they approach land. The average velocity of storms fully formed appears to be from 10 to 12 miles per hour, and this is, perhaps, the best rule for the sailor to assume. Several severe storms of recent years have advanced at the rate of 15 miles when approaching land, and the Backergunge cyclone travelled with the very great velocity of about 25 miles per hour across the mouth of the Megna. There appears to be no direct relation between the intensity of a storm and its rate of progress, and no general rule has yet been suggested which will enable the sailor to estimate from such observations as he usually is able to take during a storm its rate of motion.

Brief Summary of Chapter.—Cyclonic storms very rarely occur in the Bay of Bengal during the months of January, February and March. The cyclone season extends from April to December, during which period south-west winds

bring up cloud and rain to a part or the whole of the Bay. During a considerable part of this period, or from the 15th June to the 15th September, cyclonic storms are of frequent occurrence, but they are never very extensive or violent. They only form near the head of the Bay, and by far the larger proportion pass westwards or west-north-westwards across the Orissa Coast. They cause a high sea in the north-west angle of the Bay, and give heavy westerly to southerly gales in the north of the Bay. During the remaining two periods of the cyclone season, *viz.*, from the 1st April to the 15th of June, and from the 15th of September to the end of December (usually known as the May and October transition periods) storms are of less frequent occurrence. The majority of the storms of these two periods (about three out of five) are neither large nor violent, and are similar in character to the cyclonic storms of the rains. The remaining storms of these two transition periods (about two out of every five) are very dangerous and intense cyclones, as they have an inner storm area of hurricane winds, a very high and confused sea and strong currents around a central area of light airs and calms.

It is desirable that sailors navigating the Bay of Bengal should avoid, so far as is possible, the strong winds and high sea of all cyclonic storms; but it is especially desirable that they should avoid the inner storm area of the intense cyclones of the two transition periods. The weather is of so stormy a character in the inner storm area that no vessel, however strongly she may be built, and however well handled, can hope to pass through it unharmed. On the other hand, considering the manner in which the coasts of the Bay are now warned, the rapid publication of weather reports and charts at the two largest ports, Calcutta and Madras, as well as the extending knowledge of the laws of storms, it is hardly too much to say that there is little excuse (unless under very exceptional circumstances) for the captain of a steamer who drifts or runs into the inner area of a severe cyclonic storm. By utilising the information at his disposal, and by the exercise of judgment and prudence, he should, in the open sea, be able to avoid the inner portion of the storm area and to select a course which will keep him out of the right advancing or dangerous quadrant (more especially if he be near the west coast of the Bay), and will take him into the manageable quadrant or semi-circle of the storm.

In order to do this, it is necessary he should be able to ascertain as early as possible when a cyclonic storm has formed and is in existence in the part of the Bay he is navigating.

The indications of a distant cyclonic storm in the Bay of Bengal are as follows, in the order of their importance:—

A.—General Indications (*always observable*)—

1st.—The occurrence of a succession of squalls which increase in frequency and intensity as the storm area is approached.

2nd.—Barometric indications, including—

(*a*) The fall of the barometer more or less below its normal height.

(*b*) The continued fall of the barometer (allowance being made when necessary for change of position of the observer) as he approaches the cyclonic storm. The fall of the barometer is *never* rapid except in the inner storm area which sailors in their own interest ought never to experience.

3rd.—General appearance of the sky and weather. It is not possible to state these indications very definitely. Many of them are given in two small works published by two members of the Calcutta Pilot Service, Messrs. Elson and Lidstone.[1]

B.—Occasional Indications (*observable only under favourable circumstances*)—

1st.—The appearance of a peculiarly dense heavy bank of clouds on the horizon. This is most frequently observed in the northern quadrant where skies are clear or lightly clouded in front of the cyclonic storm.

2nd.—Peculiarly dark-red or coloured sunrises and sunsets. These are most frequently noticed to the west, north-west, north or north-east of the storm area.

3rd.—The occurrence of a heavy swell proceeding outwards from the cyclone which is fairly regular even at long distances from centre. This is more especially the case in the northern and western quadrants where it is least affected by the swell due to the wind. The swell becomes higher and more confused as the storm is approached.

When the occurrence of squalls, the sky appearances, barometric and other indications show that a cyclonic storm is in existence in the Bay, and the weather is becoming more threatening (due either to the approach of the storm or to its increasing intensity), the mariner should proceed without unnecessary delay to determine the direction and path of the storm.

The direction or bearing of the centre is obtained from the wind direction in the manner described in pages 194—5. This direction should coincide approximately with the direction of the swell due to the cyclone (if any), and also with the direction of the cyclonic bank of clouds on the horizon (if visible). The swell in the outer storm area usually comes from

[1] These books are entitled "The Sailor's East Indian Sky Interpreter and Weather Book," and "Some Practical Observations on Cyclones in the Bay of Bengal," and can be procured from Messrs. Thacker, Spiuk & Co., Publishers, Calcutta.

a direction a little to the left of the direction or bearing of the centre. The indications of the bank of clouds, and of the swell, &c., should only be used to confirm the direction or bearing of the centre as obtained from the wind direction. The mariner (if leaving the Hooghly) should also remember that the wind hangs unusually long at north-east in the north-west angle of the Bay when a cyclonic storm or cyclone is approaching that part of the Bay, and hence that the ordinary rule for finding the centre may be out as much as two or three points. As already pointed out, no rule based on wind direction alone for the bearing of the centre can be exact or satisfactory, for the measurement of the wind direction on board ship is itself liable to considerable errors, more especially in stormy weather.

Finally, when he has ascertained the bearing of the centre, he should proceed to ascertain its probable track. In order to do this the vessel should slow down or be hove to, and the first *permanent* shift of wind (evidently due to the motion of the cyclonic storm or cyclone only) will, more especially when considered in connection with weather, enable him to ascertain the track or course of the cyclone. The method of doing this is explained in pages 200—2.

CHAPTER IV.

BRIEF ACCOUNT OF EIGHT TYPICAL BAY OF BENGAL CYCLONES OR CYCLONIC STORMS.

The present chapter gives a brief account of eight typical cyclones or cyclonic storms in the Bay, *viz.*—

(1) The Calcutta cyclone of October 1864.
(2) The Backergunge cyclone of October 1876.
(3) The Midnapore cyclone of October 1874.
(4) The False Point cyclone of September 1885.
(5) The Akyab cyclone of May 1884.
(6) The cyclonic storm of 26th June to 4th July 1883.
(7) The Port Blair cyclone of November 1891.
(8) The Chittagong cyclone of October 1897.

The first two storms are examples of the largest and most intense storms which occur during the October transition period. The third and fourth storms are examples of the smaller, but equally intense, cyclonic storms which occur at the head of the Bay at the commencement of the October transition period. The fifth is an example of a storm generated during the first large advance of the south-west monsoon current up the Bay, and is remarkable for its peculiar path. The sixth is an example of the numerous class of cyclonic storms of the rains proper, and is a typical and representative example of the more severe storms of that class. The seventh, the Port Blair cyclone is remarkable not only for its origin outside the Bay of Bengal but for its very large recurvature, the path being parabolic in form. The eighth and last storm, the Chittagong cyclone of October 1897, is the most recent example of a small but intense cyclone of the October transition period. The tracks of these eight cyclonic storms are given in Plate XLVII.

THE CALCUTTA CYCLONE OF OCTOBER 1864.

The following history of this cyclone is compiled from the valuable report drawn up by Colonel Gastrell and H. F. Blanford, Esq. The report is confessedly imperfect, as meteorological observations were taken at only about half a dozen stations in India in 1864.

Weather previous to the storm.— For some days previous to the formation of the cyclone (that is from the 28th of September to the 1st of October) pressure was above the average, and was slowly and steadily rising at the coast stations of Chittagong, Calcutta, and Madras. Also the differences of pressure exhibited by these stations were comparatively small, indicating that pressure was approximately uniform over the Bay.

At the end of the month of September pressure was considerably above the normal, winds were very light, unsteady and variable at Calcutta, Chittagong and Madras, and probably over the whole of the north of the Bay and in Bengal. Unusually fine dry weather prevailed in Bengal, where little or no rain had fallen for some days. These conditions continued over the north of the Bay and in Bengal during the whole period while the

cyclone was being formed in the centre of the Bay. Ships' logs establish that strong south-west winds blew over the whole of the south of the Bay for some days before the commencement of the storm. They also show that in the neighbourhood of the Andamans, dark, squally, rainy weather set in shortly before the storm. This squally weather appears to have commenced on or about the 27th September, but did not apparently develop much until the 1st of October, when the weather became rapidly more threatening. The wind directions given in the logs of the vessels passing up the Bay at the time indicate that there was no cyclonic movement of the air on the large scale on the morning of the 1st, although the weather was squally and very threatening in appearance. They also prove that the change from irregular disturbance and squally weather to general cyclonic conditions of air movement took place during the next 24 hours, *i.e.*, on the 1st and 2nd, but was not fully completed before the evening of the 2nd.

October 2nd.—The observations taken on board three vessels and at Port Blair (in positions covering an area of about 100 miles east and west, and 150 miles north and south from Lat. 12½° N. to Lat. 14½° N. and Long. 90¼° E. to Long. 91¾° E.) show clearly the existence of the disturbed weather indicating initial cyclonic disturbance over that area on the 2nd. The logs state that squalls became more frequent and intense during the day, and that a "deluge of rain" was falling over a part, at least, of the area. The barometer was falling in the area but was not yet much below the normal. The observations on board two of the ships nearest to the centre of the area on the 2nd (*viz.*, the *Conflict* which was in about Lat. 13½° N. and Long. 90° E., and the *Moneka* in Lat. 12½° N. and Long. 90° E. at noon) show that the weather moderated very considerably during the afternoon and that the sea went down. These ships were not more than 100 to 150 miles from the centre of the area in which the storm was being generated. The *Conflict* nearest to it, had light variable winds with squalls during the morning. Apparently there was at that time a clearly marked tendency for the disturbance to pass away. It is not possible from the observations to infer the cause of this halt in the progress and growth of the storm. The observations of the 3rd show that this tendency speedily passed away, and that the storm increased very rapidly in extent and intensity on that day. So far as can be judged, it would appear that, although the storm on the 2nd was developing from the initial stage of squally, disturbed weather, it had not yet passed beyond that stage.

October 3rd.—The logs of five vessels enable the position and character of the disturbance on the 3rd to be determined. The two vessels previously referred to, *viz.*, the *Conflict*, *Moneka* and a third vessel the *Golden Horn*, had advanced 100 miles northward, but were still in the southern quadrant of the storm. Two other vessels, the *Nile* and *Clarence* were at a considerable distance to the west and north-west of the centre. The *Golden Horn* had hard squalls with

heavy rain in the morning and a deluge of rain during the afternoon. The *Conflict* had frightful squalls with very heavy rain, and the *Moneka* heavy gusts to calms with rain falling "as in a solid mass." The centre at noon of the 3rd was in about Lat. 16° N. and Long. 90¼° E. The storm area was much larger and now included a nearly circular area from 300 to 400 miles in diameter. The disturbance now began to influence the weather in Bengal. Winds which had hitherto been chiefly south (although very variable) veered round and blew steadily from north or north-east, but were as yet very light. Light cirrus clouds also began to appear in the course of the afternoon, and weather which had hitherto been fine, clear and pleasant became cloudy and slightly unsettled.

October 4th.—The position of the centre at noon of the 4th is fixed by information taken from the logs of eight vessels in the north of the Bay. The storm centre was now advancing to the mouth of the Hooghly (in a north-north-westerly direction) at the rate of 9 miles an hour. The centre was in Lat. 18° 50′ N. and Long. 88° 30′ E. at noon, and at that time two vessels, the *Golden Horn* and *Clarence* were not more than 35 miles from each other and were on opposite sides of the storm centre. The *Clarence* had "furious squalls from north, with torrents of rain," and the *Golden Horn* a heavy southerly gale with a deluge of rain. The barometer at the centre was apparently not below 29·00″ at noon of the 4th, judging by the barometric readings taken on board these two vessels. Stormy weather had now extended to the Bengal coast, and winds strengthened rapidly, rain-squalls came up and became more and more frequent, the sea rose, and the sky and weather assumed a very threatening appearance during the afternoon and evening. At the Sandheads, and entrance to the river, the fury of the storm was chiefly felt on the night of the 4th. The centre passed to the east of False Point at a distance of about 80 miles shortly before midnight. The Pilot Brig *Chinsurah* ran southwards during the afternoon, and passed a little to the west of the centre about midnight, at which time her barometer read 28·57″, having fallen one inch since the previous noon. The Pilot Brig *Foam* like the *Chinsurah* ran southwards, having slipped her cable at 4 P.M. She passed to the west of the centre but nearer than that vessel. Her log states that at 8 P.M. it was blowing a violent hurricane. At 11 P.M. the quarter-boat was washed away and the vessel thrown on her beam ends, when the main-mast was cut away. The barometer at that hour stood at 27·96″ and remained at that height until midnight, when it began to rise. From midnight to 5 A.M. of the 5th wind blew with hurricane force and then began to abate.

October 5th.—The cyclone recurved slightly to east after midnight of the 4th and advanced in a northerly direction, and at the average rate of 10 miles per hour to the Bengal coast west of Saugor Island. The centre passed over the *Alexandra* Steam Tug, which was lying at anchor off Saugor Light-house,

between 8 A.M. and 9 A.M. of the 5th. The following extract is from the captain's log:—

"At 4 A.M. the wind shifted suddenly to north-east, blowing in furious gusts, accompanied by pelting driving rain and seas over all. On coming head to wind, the engines were set going with seven revolutions, at full power. About 8 or 9 A.M. it became suddenly calm, with a heavy confused sea, the sun appearing at this time for a few minutes. Got the head of the steamer to northward, having only then discovered that the cable had parted. The frightful roar of the hurricane, the heavy sea breaking fore and aft, and the steamer lying on her beam ends prevented anything being noticed with regard to the cable before. The steamer's head was now to wind and the engines doing their best. The calm interval lasted about three-quarters of an hour. During the calm, being apparently in the vortex of the hurricane, several land birds were falling about the decks, some dead. Got soundings in 7 fathoms. Supposing the steamer to be in Saugor Roads, kept on going to the north and east, but could sight no land; secured hatches, and at the end of the calm a thick mist and heavy rollers seemed coming from north-west, accompanied by a moaning sound, which was immediately followed by a sudden blast from the north-west, throwing the steamer on her beam ends and burying her in a sheet of foam to the top of the funnel. The port jolly-boat blew over board and carried away the standard compass. The starboard boat was under water and was torn from the davits. All that could be done was to try and keep her near the wind, while heading to northward by means of the engines only, as it was impossible to think of letting go another anchor. After blowing till 2 P.M., with the most intense fury and constant heavy rain, the wind shifted to the south-west; the weather broke suddenly, water became smooth, and land appeared on the port beam. Finding the vessel in 4 fathoms, made preparation to anchor; situation very doubtful and coast strange; 3 P.M., water suddenly shoaled to 2 fathoms; the steamer struck before the engines could be reversed and in less than an hour was quite dry. About 9 P.M., as the tide made, backed off to the westward into smooth water and anchored in 4 fathoms for the night. In the morning the position was found to be off the Piply Sands in Balasore Roads. The vessel had hence been carried to the westward by the force of the current upwards of 30 miles."

Before proceeding to give the history of the cyclone after it crossed the coast, it is desirable to give the experience of two vessels, the *Proserpine* and *Nile*, which were at nearly equal distances from the centre, but in opposite quadrants, in illustration of a very important point, *viz.*, the strength of the storm in the eastern quadrant as compared with the westward quadrant. The *Proserpine* was proceeding from Calcutta to Akyab, and was, when nearest to the storm on the 4th, upwards of 180 miles from the storm centre in the eastern quadrant. On the morning of the 4th it was blowing a great gale from the east with increasing sea. The gale increased rapidly, and the sea rose with wonderful rapidity. By 3 A.M. it became too powerful for the steamer to make headway against, and she finally drifted under the force of the winds and currents, the helm being wholly unmanageable. The following extract from her log of her subsequent experience is extremely interesting:—

"6 P.M.—The gale still increasing; vessel rolling very heavily; lost the galleys; water increasing in the engine-room; kept it under as well as we were able with the ship's pumps. *Midnight.*—Sea increased to a frightful extent. Vessel labouring heavily. All the men completely knocked up. 1 A.M.—Gale still increasing, immense heavy seas breaking over the forecastle and foredeck. 3-30 A.M.—On sounding the fore compartment discovered that there was 3½ feet water in her; took off the hatch and set all hands at work to pump and bale the water out; found the lower deck washed up, and beams and planks, etc., dashing about

below, threatening to go through the side or water-tight bulkheads; sent all available hands to the pumps, as the water in the engine-room was increasing very fast; the gale appeared to be now at its height, the plunging into the seas, leaving over two feet of water on the upper deck; commenced cutting away the lower part of the bulwarks, and after great difficulty succeeded in getting several holes made which slightly relieved the immense pressure forward; cleared away the boats as much as we dared, and put water and provisions into them, as we fully expected the vessel to go down under us. Threw everything we could overboard in order to lighten her forward, the vessel being totally unmanageable the whole of this time. *Noon.*—The wind was now to the south a little, a fearful sea running. 1 P.M.—The weather began to improve a little. All were employed at the pumps, but were so exhausted as to be scarcely able to keep them going. Ship rolling and straining very severely; sea not appearing to decrease in the least. *Midnight.*—Weather seems clearing up, but there is still a fearful sea rolling. 1 A.M.—Wind and sea decreasing."

The *Nile* was in the western quadrant and at a distance of 160 miles from the centre at noon, or 20 miles nearer than the *Proserpine* when she was nearest. The following is the account of the weather she experienced as given in her log:—

"OCTOBER 4TH, A.M.—Confused sea; ship pitching at times. *Daylight.*—Weather unsettled, wind north-west; a head sea. *Forenoon.*—Wind north-west, freshening at times, with a north-north-east sea. *Noon.*—Wind north-north-west; weather cloudy. Sea uneasy. P.M.—Squally with rain. *Sunset*—Wind west-north-west; high north sea. *Midnight.*—Moderate west breeze; ship plunging heavily to a high sea."

This contrast between the weather to the north-west, west and south-west of the centre, and that to the south-east, east and north-east, is a very prominent feature in the cyclonic storms of the Bay, and should be carefully remembered by sailors.

The centre of the cyclone struck the coast near Contai. It blew at that station a north-east gale from 4 A.M. to 7-45 A.M. of the 5th, when the gale was at its height. The barometer fell from 28·95″ at 8 A.M. to 28·025″ at 9-45 A.M., when the wind suddenly fell to a calm which lasted until 11 A.M., after which the storm recommenced from the south-west, blowing a perfect whirlwind.

The history of the land passage of the cyclone will be briefly given. The next station after Contai over which the centre passed (of which there is an account) is Tamluk. A strong north-easterly breeze prevailed from the morning of the 4th until 4 A.M. of the 5th, when the wind increased rapidly in force. It was blowing a hurricane at 9 A.M., and from that time to 11-30 A.M. it continued to increase in fury. Between 11-30 A.M. and noon the storm wave came in, and the water rose speedily until noon, when the centre of the cyclone passed over the station. At that time the wind was due east. The central calm lasted rather more than half an hour, after which the wind came down from the opposite quarter. It began perceptibly to decrease in force about three hours afterwards, and at 6 P.M. was only blowing a little fresh from west.

The centre passed over Santipore in the afternoon at 5 P.M. The wind at that station blew during the early morning with no great force, but gradually increased till noon, when it was blowing a strong gale. The force of the wind

intensified rapidly for some time, blowing from the same direction as hitherto, *viz.*, east. The wind changed from east to north-east at 3 P.M., and was at the height of its violence at that time, tearing down the largest banian trees. Hurricane winds continued until 5 P.M., when the storm ceased entirely for 45 minutes and commenced again, blowing first from the west and then from the south-west. The storm centre was, at the time of its passage over Santipore, about 25 miles to the west of Calcutta. The area of destruction did not extend more than 35 or 40 miles to the west of the central track, and the storm was not felt at all beyond about twice that distance. To the east of the path of the centre, the extent over which the storm extended was considerably greater, and, so far as can be judged, at least twice as great.

After passing over Santipore the storm recurved slightly to the east, and advanced between Burdwan and Krishnagar and between Murshidabad and Kushtia. The following gives a brief account of the weather as observed at Kushtia :—

"The storm began here with heavy rain and moderate winds from the north-east about mid-day of the 5th. As the day advanced the rain gradually decreased, but the wind increased steadily, veering round still more to the eastward with fitful gusts which blew the rain into a mist. By 9 P.M. the wind was about due east, and it was now evident that something more than an ordinary gale was blowing. From this time to about 11 P.M. the storm was at its height. With very few exceptions every hut and tree was blown down, gardens destroyed, etc. The wind, while doing all this mischief, gradually veered round from east to south, and blew hardest from about the south-east. When it got fairly to the south its force was reduced, and by the time it had a little westing in it (about midnight) the storm began to abate. The storm hence lasted about twelve hours altogether."

October 6th.—The accounts of the storm after this date appear to indicate that it was breaking up, and that the cyclonic circulation was less regular than before, and probably resolving itself into smaller eddies. It is almost impossible to reconcile the different accounts except on some such supposition.

The storm passed near Bogra, where it was comparatively feeble, and finally broke up on approaching the western escarpment of the Garo Hills.

The storm wave.—The most remarkable feature of the Calcutta cyclone of 1864 was the storm wave. It was nearly full moon on October 5th. The storm wave arrived at the mouth of the Hooghly a little after 10 A.M., high water being at about noon. The storm wave apparently advanced more slowly up the Hooghly than the ordinary tidal wave, and hence at Calcutta the storm wave was only about an hour in advance of full tide. The wave therefore occurred under conditions favourable for producing a very large effect.

The enormous accumulation of water in the north-west angle of the Bay when the storm centre was crossing the coast was very strikingly shown by the experience of the ship *Martaban*. She lay at anchor in Saugor Roads on the evening of the 4th, when it was blowing a strong gale. At 5 P.M. of the 5th the wind had increased to a hurricane and the ship began to drag her anchors. The

fore-end topgallant-masts were carried away at 9-30 A.M., the main-mast at 10 A M., and the fore-topmast at 10-30 A.M., by which time the ship was a wreck on deck. The centre shortly after passed over the vessel, and was followed by a terrific wind that blew for a short time. The weather began to abate at 0-20 P.M., and cleared up rapidly. As soon as it cleared up sufficiently to enable the pilot to ascertain his position, he found that the vessel was to the west of the Jellingham sand, and had drifted over some of the most dangerous sands in the river without touching or shoaling any water. The lead was constantly used, and the ship never shoaled at less than 7 fathoms. The pilot hence estimated that the storm wave must have risen at least 40 feet to have carried him across those sands.

One point in connection with the storm wave is of great interest. It is very unlike the tidal wave, which rises gradually, and which only on favourable occasions gives rise to, and is accompanied by, a small sudden advance of a wave or wall of water or bore. In the case of the storm wave there is, for some time as the storm centre approaches the shallow waters at the head of the Bay, a large accumulation of water. This head of water finally gives rise to a sudden and overpowering advance of the accumulated mass of water up the river and an almost equally rapid inundation of the low-lying grounds near the sea shore. The following extract from the account of a Civilian who was overtaken by the flood due to the storm wave whilst on his way to Midnapore illustrates this feature of the storm wave on the Bengal coast:—

"I took shelter in a hut. Soon I heard my bearers talking in a frightened manner with a few stray villagers. They then nervously asked the time. I told them just past noon. They said that at half past twelve a high bore was to be expected. We watched as much as we could, for it was difficult to see 20 yards off through the driving rain, or rather mist. Sure enough, though I did not see any actual bore, the water *all at once suddenly rose as if by magic, and steadily rolled towards us.*"

The storm wave flooded the whole of the low-lying ground in the neighbourhood of the Hooghly as far up as Akra in Kidderpore, and the lower reach of the Roopnarayan river to above Koila Ghât, sweeping all before it by the suddenness of its rush and by the immense volume of water. The following gives a brief account of the destruction of life in the submerged districts:—

Loss of life during the flood (approximate)	50,000
Loss by disease due directly to the flood	25,000 to 30,000
TOTAL LOSS OF LIFE DIRECTLY AND INDIRECTLY CAUSED BY THE STORM .	80,000

The destruction of shipping in the Port of Calcutta appears to have greatly exceeded that on record for any previous storm. There were, on the 5th Octo-

ber, 195 vessels in port, either at their moorings or at anchor in the stream. The moorings were held by anchors of 65 and 70 cwt.; and the chains laid down after the cyclone of 1842 were of the heaviest construction. At the same time new posts of sâl wood for shore fastenings, 22 feet long by 2 feet square, were fixed along the river bank. It appears, however, that the moorings were of insufficient length, and thus the rise of the river, due to the storm wave, brought an additional strain on the chains already stretched to their utmost under the pressure of the cyclone winds, which caused many of the ships to break loose. They drifted before the blast, carrying before them many of those that had ridden out the storm so far safely in midstream, and were grounded, a mass of confused wreck, with cargo-boats, lighters, and smaller boats of every description, on the sands of Goosery, Shibpore, and Cossipore. Of the whole number above mentioned, only 23 were uninjured on the morning of the 6th October; 39 were damaged but slightly, 97 damaged severely, and 36 were totally lost or had suffered so severely as to become constructively wrecks. Among these last were the *Azemia*, 1,179 tons, the *Govindpore*, 1,357 tons, the *Lady Franklin*, 1,187 tons, the *Lewchew*, 854 tons, the *Ville de St. Pierre*, 379 tons, the *Vespasian*, 919 tons, which sank off Calcutta, the *Baron Renfrew*, 904 tons, which was lost near Diamond Harbour, and the *Ally*, 665 tons, a cooly emigrant ship, which foundered with the almost total loss of the crew and emigrants, 15 miles below the same station. A considerable quantity of cargo, both on board the ships and on cargo-boats, was either swept away or had to be sacrificed to lighten the vessels. Wrecked property, to the estimated value of R57,000, was rescued by the Police in the town and suburbs of Howrah alone, but the Superintendent of Police was of opinion that, in spite of all exertions, a vast amount was taken and concealed by the ryots, many of whom it was said, far from suffering by the cyclone, became suddenly wealthy. The banks of the river at Cossipore were, for weeks subsequent to the cyclone, thickly strewn with masses of jute beneath and among the pack of stranded wrecks.

The Peninsular and Oriental Company's steamer *Bengal*, 2,185 tons, was landed high and dry on Shalimar Point, where she remained a conspicuous object for more than two months, when she was at length restored to deep water by cutting a dock around her, and towing her out at vast expense. The *Hindustan*, receiving hulk, the property of the same Company, was partly driven on shore, but foundered next morning.

No reliable estimate has been formed of the total value of the shipping and cargo lost or damaged in the port. It was stated at the time to be about two million pounds sterling, but this was apparently no more than a vague guess at the amount, and much over-estimated. Mr. R. Stewart, a partner of Messrs. Gladstone and Wylie's house, considers that this estimate more nearly represents the gross value of the shipping property at stake, and that the actual loss was considerably under one million sterling.

Brief summary of chief facts.—The storm was formed during the 1st and 2nd of October in about Lat. 13° N. and Long. 91½° E., or about 100 miles to the west of the Andamans, and marched in a north-north-west course to the mouth of the Hooghly, and thence advanced into Central Bengal, curving round to north-north-east and north-east in its progress through South-west and Central Bengal. The following gives the position of the storm centre at various intervals during the storm and the rate of motion:—

Time.	Position of Storm Centre.		Distance travelled since last previous position.	Rate of motion during interval.
	Latitude.	Longitude.		
			Miles.	
October 2nd, noon	13° 15′ N.	91° 40′ E.	...	...
" 3rd "	16° N.	90° 15′ E.	215	9 miles per hour.
" 4th "	18° 50′ N.	88° 30′ E.	220	9 " "
" " midnight	20° 20′ N.	87° 45′ E.	115	10 " "
" 5th 10 A.M.	Contai	...	96	10 " "
" " noon	Tamluk	...	35	18 " "
" " 5 P.M.	Santipore	...	75	15 " "
" 6th, 1 A.M.	Near Rampur Boalia.	...	75	9 " "

Its rate of motion hence apparently never exceeded 10 miles per hour in the Bay of Bengal, and it did not increase its speed as it approached the Bengal Coast, in which respect it differed from the Backergunge, Midnapore, False Point, and other intense cyclonic storms of recent years. Its rate of motion, however, increased very rapidly for some time after it crossed the Bengal Coast, and it advanced at a rate of at least 15 miles through West Bengal. It decreased to its former rate of about 10 miles per hour in passing through Central Bengal.

The lowest observed reading of the barometer during the storm was 27·96″ (corrected), taken on board the *Foam*.

The central calm area on the evening of the 4th and morning of the 5th when it was probably greatest, was elliptical-shaped, and from 10 to 15 miles in diameter.

The following gives the few reliable data of the direction of the wind as related to the bearing of the storm centre:—

Ship.	Date.	Distance and bearing of centre.	Wind direction.	Bearing Angle.
Conflict	October 4th, noon	280 miles west by north	S. E.	146°
Nile	" "	100 " north-east	W. N. W.	112°
Clarence	" "	30 " east-south-east	N.	112°
Proserpine	" "	190 " south-west	E.	135°

The reliable observations of positions of vessels involved in this storm and of wind-force are very few in number, but, such as they are, they give a mean bearing angle of 126°, or 11 points very nearly.

The Backergunge Cyclone of October 1876.

The Backergunge cyclone was the largest and most destructive to life that has occurred during the present century. A smaller cyclone, which formed during the first week of the month of October 1876, passed over Vizagapatam on the 8th, recurved, and marched between the coast and the hills of Ganjam and Orissa into Bengal, where it finally broke up on the evening of the 10th or morning of the 11th in the neighbourhood of the Himalayas in North Bihar and North Bengal.

Weather previous to the formation of the cyclonic storm.—The barometer rose rapidly after the dispersion of the Vizagapatam cyclone, and was during the next fortnight very considerably above its normal height. The excess was greatest in the east and south-east of the Bay, or over that portion of the Bay where the cyclone was very shortly afterwards formed. The mean temperature of the air was from 2° to 7° below the average of the season in Northern India, but was slightly above it at Port Blair and Madras and probably over the south and centre of the Bay, where the weather was very sultry. Fine dry cool weather, with cloudless skies and light airs, prevailed almost without interruption in Northern India. During this period the winds in Bengal, which had been previously southerly, shifted round to their cold-weather directions, and the winds and weather at the end of the third week of October were such as prevail when the north-east monsoon is fully established over the north of the Bay. Pressure was remarkably uniform over the Bay, and in Northern and Central India.

The weather in the south and centre of the Bay at this time is described in the logs of three vessels. The ship *Lightning* crossed the Equator on the 12th in Long. 88½° E., and advanced very slowly northwards up the centre of the Bay, reaching Lat. 9° 17′ N. on the 23rd. During this interval she experienced very light winds and calms, with showers of rain and hot sultry weather, the sun being so hot as to boil the pitch out of the seams of the deck. The *Tennyson* crossed the Equator in Long. 89° 40′ E. on the 13th and was in Lat. 13° N. on the 26th. She experienced light baffling winds with heavy rain during the whole of this period, *i.e.* until the 26th, on which day the wind veered to north-east and the weather cleared up. The *City of Venice* passed round Ceylon on the 26th. She had light breezes, and weather was fine and clear to the west and south of Ceylon, and in this respect unlike the weather in the eastern half of the entrance to the Bay. From the 20th to the 27th or 28th the weather in the north of the Bay was of the same character as in Bengal. In the south-east of the Bay, as is indicated by the Port Blair, Nancowry and ship observations, weather was unsettled, and the winds were very variable and unsteady. Much rain was falling, and squalls were of occasional occurrence. No change took place in that area of slightly unsettled weather until the 24th

and 25th, when the first indication of cyclonic movement of the air on the large scale began to be exhibited. The cyclonic movement was comparatively feeble between the 24th and 26th, and showed no marked tendency to increase and concentrate.

The following extracts from the logs of ships give the character of the weather in the south and centre of the Bay from the 24th to 26th:—

The *Tennyson* crossed the Equator on the 13th, in Long. 89° 40′ E., and advanced northwards over the area in which the storm was immediately afterwards formed. She had light baffling winds chiefly from west with heavy rain until the 26th, when, in Lat. 13° N., the weather cleared and the wind veered to north-east.

The *Lightning* advanced during the period October 23rd to 26th from Lat. 9° 17′ N. to about Lat. 16½° N. During these four days she had fine weather and light north-east to east-north-east winds. There were, however, during the whole of this period in the south-east quarter, disagreeable-looking cumulus and nimbus clouds which appeared to the captain to be indicative of a storm. Every evening there was much threatening lightning in an archway from the south-east up to about 40°, then crossing over to the south-west.

The whole of the data show that there was a very slight tendency on the 23rd and 24th to the establishment of an area of low pressure in the centre of the Bay to the west of the Andamans, over which weather was unsettled and threatening. Pressure was fairly steady, but the tendency continued to be exhibited on the 25th. The *Tennyson*, which traversed this area on that day, had light winds and a steady barometer. She passed out of it on the 26th in Lat. 13° N. and then experienced ordinary north-east monsoon weather until she was overtaken by the cyclone on the 30th. The *Lightning* passed also through the area in which the cyclone was initiated on the 23rd and 24th, or two days earlier than the *Tennyson*. She had very hot, fine weather, very light winds and occasional showers. The weather was slightly unsettled at the Nicobars and Andamans and winds were, as in the Bay, light. The average daily amount of wind from the 23rd to the 25th at the Nicobars was only 50 miles, or barely 2 miles per hour. Light showers fell at intervals, and skies were more or less clouded. In fact the weather was almost identical with that experienced by the *Lightning*. On the evening of the 25th and morning of the 26th a rapid and significant increase took place in the force of the wind at the Nicobars, which was coincident with the commencement of rapidly increasing cyclonic circulation on the large scale over the centre of the Bay. The history of the storm proper hence dates from the evening of the 25th.

History of the Storm.—*October 26th.*—No ships were in the storm area on the 26th. The *City of Venice* which was passing round the eastern coast of Ceylon, experienced light breezes and heavy rain, with occasional severe

squalls and unsettled weather. The amount of wind registered at Nancowry for the 24 hours preceding 10 A.M. of the 26th was 254 miles, and for the next 24 hours was 310 miles.

October 27th.—The history of the cyclone will now be given chiefly by means of brief extracts from the logs of ships involved in it. A remarkable feature in the history of the storm is that, although there were an unusually large number of vessels in the Bay passing up to the Hooghly, not a single vessel was involved in the storm centre. This was largely due to the fact that the cyclone recurved to the north-north-east and advanced towards the mouth of the Megna, so that vessels bound for the Hooghly were all in the western quadrant and at some distance from the centre. Hence, also, neither the greatest barometric depression at the centre nor the full weight of the storm near the centre is known, and can only be inferred from the magnitude of the storm wave which followed and broke upon the coast districts at the mouth of the Megna. The observations of the 27th show that there was a clearly-marked depression, the centre of which was to the west of the Andamans in Lat. 10° N. and Long. 89° E., and that over this area winds were cyclonic in direction, but were as yet of moderate intensity. The ships *Empire of Peace* and *British Sceptre* were to the south-east of the central depression during the day. The former experienced thick cloudy weather, much rain and moderate winds from south-south-west to south-west. The latter (nearer to the centre) had strong breezes during the day and a deluge of rain. The *Arabia* to the west of the centre had constant rain and occasional squalls. The ships *Tennyson* and *Forfarshire* (250 miles to the north-north-west) had fine clear weather with moderate north-east winds. Moderately strong cyclonic winds were blowing at Port Blair and Nancowry. Skies were thickly clouded, and heavy rain fell during the day.

October 28th.—The cyclone developed rapidly in intensity and extent on the 28th. Torrential rain fell over a large part of the area of depression, and frequent squalls occurred, and the winds near the centre strengthened rapidly. The *British Sceptre*, 200 miles to the east-north-east of the centre, had torrents of rain at noon, the *Empire of Peace* (180 miles to the east-north-east at noon) strong breezes with much rain, and the *Allahabad* (150 miles to the east-north-east) constant rain and heavy squalls. The *City of Venice*, to the west-south-west of the centre at noon, had frequent squalls of wind in the morning. At noon there was a fresh breeze, with heavy squalls. At 8 P. M. the wind had increased to a fresh gale, and at midnight it blew a hard gale, with hard squalls.

October 29th.—The centre of the depression advanced during the 24 hours preceding noon of the 29th to Lat. 13° N., Long. 89° E., or a distance of about 120 miles, and was nearly 150 miles due west of Port Blair. The area of depression at mid-day of the 29th covered a large area, extending from Lat. 6° N. to Lat. 18° N., and from Long. 92° E. to Long. 83° or 84° E. in which winds

were of force 6 or upwards, and squalls were experienced. The ship *British Sceptre* (250 miles to the north-east of the centre at noon of the 29th) experienced torrents of rain and hard squalls, the *Allahabad* (270 miles to the north-east) constant rain with very heavy squalls, and the *City of Venice* (280 miles to the west-north-west of the centre) had an unceasing gale with continuous rain during the morning. The captain of the *City of Venice*, states that the winds and squalls increased in force, and that at 4 P.M. it blew a hard gale, with furious squalls. The logs of several vessels, which were approaching the mouth of the Hooghly at this time describe the weather as threatening in the north of the Bay, and show that strong winds and squalls were felt as far north as Lat. 18° N. in the morning. Before nightfall the weather had become unsettled and squally as far north as Lat. 20° N., and the appearance of the sky was such as to suggest the speedy occurrence of stormy, cyclonic weather.

October 30th.—The full development of the storm took place during the evening of the 29th and morning of the 30th. The land observations and the ships' logs show that on the morning of the 30th violent cyclonic motion of the air (in which winds of force 9 to 12 with frequent hard squalls obtained) extended over an elliptical-shaped area (250 miles by 200 miles), the centre of which at noon was in about Lat. 14½° N. and Long. 89¼° E.

The path of the cyclone up the Bay on the 30th and 31st, and the severity of the storm, will be best understood from the experience of each of the vessels involved in the more dangerous portions of the cyclone.

The *City of Venice* was in the outer storm area at a distance of about 300 miles from the centre at noon. She experienced a hard gale, with fierce squalls during the evening of the 29th, and at 9-20 A.M. of the 30th the weather was so threatening that the captain turned the ship's head to the south-west for some hours, and thus avoided the intensity of the storm.

The cyclone was at this time advancing northwards at a mean rate of nearly 10 miles per hour.

October 31st.—The steam-ship *Penang* was involved in the storm on the morning of the 31st. She left Calcutta on the 28th and steamed southwards into the teeth of the advancing cyclone. She experienced very rough weather on the 30th. The wind increased rapidly, and the barometer began to fall quickly on the evening of the 30th, and was at its lowest at 4 A.M. of the 31st. At 6 P.M. of the 30th the ship was taking huge seas on board, and the deck midship house and port saloon door were stove in. At 8 P.M. the starboard saloon door was broken in and the saloon flooded with water. At 10 P.M., the engineer and engine-room crew were battened down below, and the fore and main rooms and mizen gaff were blown adrift. At 4 A M. of the 31st the gig was washed away. Wind and sea were then at their highest and it was impossible to walk or stand on deck. At 7-30 A.M. the whole of the front of the saloon was stove in. The ship lay like a log, with the saloon full of water. All the head-

boards, knees, and gangways were now washed away. The barometer was at its lowest (29·32″) from 4 A.M. to 7-30 A.M., and the weather began to improve at 8. A.M. The ship was, however, found on the 1st to be a complete wreck on deck and it was judged necessary to put back to Calcutta. The *Penang* was at 7 A.M. of the 31st, when nearest to the centre, at a distance of about 150 miles from it.

The *Scottish Chieftain* encountered the cyclone a little further to the north. She arrived at the head of the Bay on the 29th and was unable to obtain a pilot in consequence of the strong winds and heavy sea. She therefore stood off to the south-east on the 30th. The gale (from the north-east) increased rapidly in the afternoon and evening, and the squalls became more frequent and heavy. At 3 A M. of the 31st the barometer read 29·2″. Heavy rain began to fall at 4 A.M., and terrific squalls from the north passed over the vessel. At 8 A.M. it was blowing a perfect hurricane. The sea now washed away everything on deck and filled the cabins. The barometer stood at 29·1″ at 10 A.M. The wind was at that time from north and blowing a hurricane, and the ship was on her beam ends. At 11-30 A.M. it was necessary to cut away the foretop-mast. The barometer was lowest at noon, when it stood at 29·00″ (corrected 28·96″). The wind was than terrific, and the lee rails of the vessel continually under water. The weather moderated slowly during the afternoon and evening. The *Scottish Chieftain* was nearest the centre at noon, but was even then probably at a distance of 80 or 100 miles from it.

The *Tennyson* was about 20 miles to the west of the storm centre at 1-30 P.M. on the 31st. She was proceeding up the Bay to the mouth of the Hooghly along the meridian of 89° E. in front of the storm on the 29th and 30th. She had passed through the area in which the storm was generated only a few days previously and began to experience squalls and increasing winds on the afternoon of the 29th. Weather became steadily worse on the 30th, and at 10 P.M it blew in furious squalls for an hour. This was followed by a brief lull, when a very violent squall from the east-north-east threw the ship on her beam ends until the first rush of the squall was past. The wind blew with hurricane force from the east-north-east from midnight (when the barometer was 29·6″) until 9-30 A.M., when it veered gradually to north, and the noise of the wind became a perfect howl. The sails were now torn from their gaskets and went to ribbons in a few minutes. The sea was a scene of the wildest confusion. The ship was thrown on her beam ends, and the sea, breaking on board, swept away everything and left her a wreck on deck. The barometer was lowest at 1-30 P.M., when it stood at 28·15 (corrected reading 28·82″). The weather began to moderate at 6 P.M., and at midnight it had died away to a calm. The top of the sea was blown about during the storm so as to make it impossible to see 20 yards from the ship.

The storm centre at noon of the 31st was moving at the rate of about 12 miles per hour, and was in Lat. 18° 45′ N., and Long. 89° 25′ E. at 1 P.M.

The *Annie Fleming* was, at 4 P.M., nearest to the centre, which was at that hour in Lat. 19° 15′ N. and Long. 89° 30′ E., and was about 50 miles to the west of it. She had arrived at the Sandheads on the 29th, but was unable to obtain a pilot. The captain stood off to the south-east on the 30th on account of the weather. At 8 P.M. of the 30th the barometer was 29·2″ and falling rapidly. At 7 A.M. of the 31st, the barometer had fallen to 28·6″, and the wind was blowing with hurricane force. At 2 P.M. there was a most terrific burst of wind, which carried away part of the rigging and sails. The ship was now on her beam ends. The barometer stood at 28·5″ from 2 P.M. to 4 P.M. when it began to rise and the weather to moderate.

The steam-ship *Thessalus* was about 90 miles to the west of the centre at 4 P.M. She had reached the head of the Bay on the 30th. The captain states that up to early morning of the 31st the barometer gave no indication of anything serious, and did not begin to fall until it was too late to do anything. At 5 A.M. the sea was terrific. At 10 A.M. the sails were carried away, and at 2-30 P.M. the main topgallant-mast went. The sea at that time was wild beyond description, the ship putting her lee side under water at times up to the dead-eyes of the lower rigging, and the wind occasionally made the masts bend like bamboos. The rain fell with such force as to be very painful to the eyes, and made it almost impossible to see. The weather was at its worst at about 4 P.M., when the barometer stood at 29·05″. It moderated rapidly after that hour and the sea fell very fast indeed, so that on Wednesday (the 1st of November) there was not the least indication of a great storm having passed over that part of the Bay.

The *Lady Octavia* and *Palmas* were nearest the centre at 6 P.M., when it was in Lat. 19° 45′ N. and Long. 89° 50′, or Long. 90° E., and advancing at a rate of 15 miles per hour in a north-north-easterly direction. The former was then about 25 miles and the latter 35 miles to the west of the centre.

The *Lady Octavia* was, on the 29th, sailing northwards to Calcutta, and was at noon in Lat. 19° 33′ N., and Long. 90° 14′ E. She had heavy rain and variable winds on that day. The weather became rapidly worse on the 30th, and towards evening she was turned southwards. The barometer at 2 A.M. of the 31st stood at 29·8″ (uncorrected). At noon the wind was blowing with hurricane force, and a fearfully high and cross sea running. At 5 P.M. the main topsail blew to pieces. The captain describes his experience of the storm from that hour as follows:—

"At 5-15 P.M. the fore top-gallant mast parted at the cap; cut away the gear to save the other spars, but was scarcely on deck when away went the main mast, and after it the mizen top-gallant mast, carrying away the top-mast head by the shrouds; lee crojjack and topsail braces gone, and the sails all blowing from the gaskets; main and main topsail braces

and the fore and fore-topsail braces carried away. The ship at 5-30 P.M. was pressed down to the lee rails, and nearly all the lee bulwarks washed away, the sea making a clean breach over her and sweeping away everything from the decks It smashed in the front of the poop and cleared out the cabins, carrying away ship's chronometers, charts, and papers, all the captain's clothing and property, and left nothing belonging to the captain's wife and son (who were on board) but what they wore. The steward and the second and third mates lost everything, and the steward's store-rooms were completely gutted out. The first mate was washed overboard and got his hand hurt among the lee wreck, his fore-finger, being cut off by the first joint. He was washed into the fore rigging, and had to cross over to windward by the top and down the weather rigging. The top was then smashed all away, the yards tearing up everything they fetched against. The wind was then blowing with such force that it was nearly impossible to squeeze down between it and shrouds. About this time the lee side of the deck-house was under water, and the whole house gutted, with all the petty officers' and boys' clothing ; the starboard side of forecastle and lockers and the cook's galley gutted out ; the captain's gig was carried away from the davits, and one davit wrenched off from the side ; the starboard life-boat was also swept away from the chocks and the long-boat started from the top of the deck-house ; all spare sails were swept out of the sail lockers ; boatswains and carpenter's stores were also carried away. At 7-30 P.M. the lightning began to flash very near, and soon the wind lulled a little and backed into north-west.

"The barometer fell from 29·50 at noon to 28·15 at 5-30 P.M.

"At about 6 P.M. the barometer got broken, and the glass of the aneroid cracked. All the meteorological instruments and books were shortly after broken up and washed away. At 8 P.M. the gale began to moderate and sea to go down."

The experiences on board the ship *Palmas* are equally valuable and interesting. The following give the most important extract from her log :—

"Left Negapatam on the 12th October bound for Calcutta, and was near the Eastern Channel light-ship on the 30th. At midnight the barometer began to fall rapidly, and the weather looked very theatening, and all preparations were made for a strong gale. At noon of the 31st it was blowing a hard gale. By this time found it must be an approaching cyclone. The ship was evidently in the north-west quarter of a cyclone, travelling from south-south-west to north-north-east. At 2 P.M. the heavy sea and lurches (assisted by the quantity of water gone below) caused the sand ballast to shift to starboard, giving the ship a heavy list to leeward. With the heavy lurching the 90 fathoms of starboard chain broke adrift, and was thrown on the lee gunwale, and at the same time all the sails and provisions, &c., on the weather side of the fore cabin were thrown to leeward, throwing the ship almost on her beam ends. We slacked away fore and main topsail sheets to try and right her, the fore one blowing away in the act, and had to slack off the main topsail sheets till it blew away. We squared the main and cross-jack yard and put the helm up to try and put her on the other tack to get the low side up, although we were already on the right tack for the cyclone, but the ship would not pay off, but continued to come up as the wind was hauling more northerly and causing the heavy south-south-west sea to break in over our lee rails and poop, and endanger the safety of the ship by knocking against the hatches. When in this position, cut away topgallant back stays, the masts going over with their gear and fouling the top-sail yards. We could not cut them clear, as all the wire got twisted and turned together. At 4 P.M. the cyclone was increasing ; barometer 28·50″, the sand still shifting to leeward and putting the ship on her beam ends. I saw then that the next thing to cutting the masts away would be to let go the starboard anchor, and let it run the 90 fathoms chain from the lee side. I went forward with the chief officer and saw all clear, and let it go, taking the 90 fathoms chain with it. The ship then righted a great deal, and less sea came over the rails. We then had a chance to go below to trim some of the ballast, and I sent all hands below for that purpose, leaving the carpenter, sailmaker, and one man on the deck to look out for the hatches and tarpaulins. In the meantime the top-gallant masts and yards were swinging about and cutting the topsails and courses

adrift from the gaskets and causing them to be blown away. At 6 P.M., when the barometer stood at 28·20″, we had the heaviest blow. The centre of the cyclone was then passing about 40 miles" (this was the captain's estimate and almost exactly correct) "to the eastward, the wind hauling to north-north-west and north-west with fearful vivid flashes of lightning, thunder, and rain. At this time the whole of the remains of our sails were blown away. The foretop-gallant yard had by this time got down, end on alongside, and knocked against the side and chafed very much, but could not cut it clear. At 7 P.M., the gale abating, we ceased trimming, the men being all tired and worn out, and the south-south-west sea being then nearly aft, ship heading up north-east by north and rolling much less. 3 P.M., gale moderating and, the barometer having risen to 28·50″, let all hands go to rest and get ready for the next day's work, to clear the wreck and trim ballast. *Midnight,* the weather clearing and wind moderating."

The *Neva* was the next vessel in order of time which encountered the full weight of the storm. She was bound from Mauritius to Calcutta and was advancing up the east of the Bay. She had, at noon of the 30th, a strong increasing gale and a mountainous sea from the south. At 8 P.M. heavy squalls, with torrents of rain, passed over the vessel. Similar weather continued during the night, and at noon of the 31st the wind was blowing with hurricane force. The wind became more violent, and at 10 P.M. was blowing with terrific force, and the sails, which had been made fast with extra gaskets and lines, were now all carried away. At 11 P.M. the wind was blowing a terrific hurricane, with tremendous gusts, accompanied with torrents of rain, and the ship was taking in large quantities of water. At 2 A.M. of the 1st the wind began to moderate. At noon she had light breezes, beautiful fine weather, and a very smooth sea.

The British India Steam Navigation Company's steam-ship *Moulmein* left Chittagong for Calcutta on the afternoon of the 30th. She hence crossed directly in front of the advancing storm. The following gives the chief details of the storm as experienced on board:—

"*Noon of the 31st.*—Wind north-east, with heavy confused sea. 4 P.M.—Wind now blowing a hurricane. 5 P.M.—Fore-topmast carried away. 7 P.M.—Foremast carried away close to deck. Spray blowing right over the ship; standard and steering compasses blown away. 10 P.M.—Wind north-north-east. Funnel carried away. Main topmast carried away. Fires put out and the boiler ran dry. The engines not able to work, and three feet of water in the tokehole, with all pumps choked. The barometer at 8 P.M. was 28·4″, the lowest reading taken. From 11 P.M. the wind began to decrease."

The *Allahabad* was about 80 miles from the centre in the opposite quadrant to the *Moulmein* at the time when that vessel was nearest to it. Her log states that—

"At noon of the 30th, when in Lat. 17° 57′ N. and Long. 91° 40′ E., constant rain was falling, with frequent very heavy squalls. A very heavy swell came up from south-south-west and south-west. 8 P.M.—Weather looked bad and threatening, with every indication of a cyclone. At 11 P.M. it was blowing a heavy gale from east-south-east, and a strong current setting northwards. At midnight it was blowing a very hard gale with constant rain, very heavy squalls, and much lightning to the southward. The squalls increased in force during the morning of the 31st, and at noon the cyclone commenced to blow with great fury and continued with no abatement until midnight. At 8 P.M. the wind began to veer to south-east. At 10 P.M., when the wind was at south-south-east to south, the cyclone was at its fiercest. It

was then blowing with inconceivable fury. The sails were torn from their gaskets, and the canvas in the mizen rigging blown away. The wind began to moderate after midnight, and the sea went down fast, and at noon on Wednesday the weather was beautifully fine."

The centre at 9 P.M., about which time it was nearest to the *Moulmein*, was in Lat. 20° 30' N. and Long. 90° 25' E., and had been moving during the previous three hours at the rate of 21 miles per hour in a north-easterly direction. It continued to advance with accelerating velocity, and was at about 85 miles to the west-north-west of the *Neva* at 11 P.M.

November 1st.—One peculiarity of the Backergunge cyclone was the rapid increase in its rate of advance as it marched northwards, more especially on the 31st. During the last five or six hours before it struck the coast it was marching at the mean rate of about 22 miles. It struck the coast at the mouth of the Megna. The centre passed over the island of Huttyah between 3 and 3-30 A.M. over the island of Siddhi between 3-30 and 4 A.M., and over the South Bamni district between 4-30 and 5 A.M. The vortex, or calm centre, appears to have been elliptical-shaped, the largest axis running perpendicular to the direction of motion, and was probably 16 miles in length, whilst the shortest in the direction of motion was from 8 to 10 miles in length.

The later history of the Backergunge cyclone is unusually brief. The centre passed over Noakhally at about 4 A.M. and over Dewangunj at 5 A.M. where the calm interval was very short. It was then advancing in a north-east direction to the Tipperah Hills. They lay at right angles to, or across, the direction of motion of the approaching cyclone, and acted not only as a perfect barrier, but as an obstruction which completely broke up the cyclonic motion before 10 A.M. of the 1st.

The storm wave.—The most remarkable feature of the Backergunge cyclone was the enormous storm wave which it drove over the islands and low lands at and near the mouth of the Megna. The inundation was due to an unusually high tidal wave, followed very shortly afterwards by the storm wave. It was full moon on the evening of the 31st, and there was hence a spring tide which flooded the low-lying land at the head of the Bay. High water was due at Chittagong at 0-30 A.M., and in the mouth of the Megna from 1 A.M. to 2 A.M. The pressure of the advancing storm wave prevented the tidal and river water flowing off. The storm wave was hence retarded over the shallow water near the entrance to the Megna and accumulated there and finally overpowered the down-flowing waters, and rushed with irresistible force over the islands, and low-lying coast districts, covering them to the depth of from 10 to 30 or 40 feet in the course of a very short space of time, probably less than half an hour. The waters receded very quickly as the storm passed inland and began to break up, and at 8 A.M. they had entirely retreated, after having destroyed all the crops and drowned a very large proportion of the inhabitants. The first estimate of the destruction of the life was given as about 200,000. A later, and

probably more correct, account puts the loss of life by drowning at 100,000, and the loss subsequently by disease (chiefly cholera), directly due to the inundation, as 100,000. It is therefore probably not too much to say that the storm wave caused directly or indirectly the death of nearly a quarter of a million of people.

Brief summary of chief facts.—The following gives the most important details of the storm :—

The cyclone apparently formed on the 25th, 26th, and 27th to the west of the Andamans in Lat. 10° N. and Long. 89° E., and moved first northwards and then gradually recurved to north-east. The position of the centre at various times and its average rate of the motion are given below—

Date.	Position.		Distance passed over since last previous position.	Average rate of motion during interval.
	Latitude.	Longitude.		
27th, noon . . .	10° N.	89° E.	90	4 miles per hour.
28th, „ . . .	11¼° N.	89° E.		
29th, „ . . .	13° N.	89° E.	120	5 „
30th, „ . .	14½° N.	89¼° E.	105	4 „
31st, 1 P.M. . . .	18° 45′ N.	89° 25′ E.	294	12 „
„ 6 „ . . .	19° 45′ N.	89° 50′ E.	75	15 „
„ 9 „ . . .	20° 30′ N.	90° 25′ E.	62	21 „
1st, 3 A.M. . . .	22° 30′ N.	91° 0′ E.	144	24 „

One of the more remarkable features of the storm was the very great increase of its velocity on approaching the coast of East Bengal.

It reached the mouth of the Megna about 3 A.M. of the 1st of November. The central calm was then from 15 to 18 miles in its longest diameter, and was probably elliptically-shaped, the longest diameter being nearly perpendicular or oval to the direction of motion.

The cyclone was completely broken up before 10 A.M. of the same day by the action of the hills in Eastern Bengal and South Assam. It extended, at sea over a very large area, blowing with hurricane force, and disabling vessels at a distance of 200 miles from the vortex, and was the most extensive as well as one of the fiercest cyclones of the present century.

The lowest readings of the barometer observed during the storm were—

28·15″ (uncorrected) on board the *Tennyson* (20 miles to west of centre).

28·15″ (uncorrected) on board the *Lady Octavia* (20 to 25 miles west of centre).

28·2″ (uncorrected) on board the *British Statesman* (20 miles west of centre).

28·2″ (uncorrected) on board the *Palmas* (35 miles west of centre).

28·4″ (uncorrected) on board the *Moulmein* (45 miles north-north-west of centre).

It is hence almost certain that the barometer was below 28 inches in the central area, and may have been at least as low as 27·5 inches, or even lower.

The following table gives data of the direction of the wind, the bearing of the centre, and the bearing angle for a large number of cases:—

Position of observation.	Date.	Approximate distance from centre.	Approximate bearing of centre.	Wind direction.	Bearing angle.	Weather.
		Miles.			°	
Tennyson	27th, noon	350	S.	N.-E.	135	Fine steady breeze.
Port Blair	„	275	W.-S.-W.	E.	160	Gloomy.
Nancowry	„	350	W.-N.-W.	S.-S.-W.	90	Rain.
Empire of Peace	28th, noon	175	W. by S.	S.-E.	124	Torrents of rain.
City of Venice	„	310	E.	N.	90	Do.
Port Blair	„	250	W.	S.-E.	135	Gloomy.
Nancowry	„	400	N.-W. by W.	S.-S.-W.	101	Passing showers.
Allahabad	29th, noon	250	S.-W. by W.	S.-E.	101	Heavy squalls.
Port Blair	„	270	W.-N.-W.	S.-E.	157	Gloomy.
Nancowry	„	475	N.-W.	S.-W.	90	Overcast.
Japan	„	410	N.-E. by E.	W.-N.-W.	124	Squally.
Japan	30th, noon	300	N.-E. by E.	W.-N.-W.	124	Do.
City of Venice	„	260	E.	N. by W.	101	Strong gale.
Nancowry	„	540	N.-W. by N.	S.-W.	101	Passing clouds.
Empire of Peace	31st, noon	125	W.-S.-W.	E.-S.-E.	135	Cyclone
Japan	„	175	N.-E.	W.-N.-W.	112	Light breeze.

The average of the various values of the bearing angle is 118°, or 10½ points very nearly.

THE MIDNAPORE CYCLONE OF OCTOBER 13TH TO 17TH, 1874.

This was an example of a cyclonic storm of small diameter and extent, but of very great intensity at and near the centre. The information derived from ships' logs respecting its origin and early march is scanty, but yet sufficient to enable its chief features to be determined with approximate accuracy.

Weather previous to the storm.—For some days previously (from the 1st October) the winds in Bengal and Orissa and over the north of the Bay were extremely light and variable, and calms were of frequent occurrence. The barometer, as usual at the commencement of October, rose steadily, and almost without interruption, from the 1st to the 10th, when pressure was either normal in amount or slightly above the average value of that period.

During the first ten days of the month the weather was fine, with passing clouds. Showers fell locally in Bengal, but no general rain was received over any large area. The rainfall due to these local showers diminished in amount up to the 10th, when it practically ceased until the advent of the storm, so that the period from the 10th to the 14th was almost rainless in Northern India. Fine clear weather prevailed over nearly the whole of Bengal at this time. The temperature was from 1° to 2° above the normal, and winds had died down, especially in West Bengal, to the lightest airs. Mr. Wilson, in his Report on the Cyclone, sums up the character of the weather in Bengal in the following words: "It was such as is usual at the time of year, light variable winds or calms prevailing, with a clear transparent atmosphere, and a blue sky, partially covered with cirrus and cumulus."

The weather in the south-east of the Bay was very different, and such as invariably precedes the formation of a cyclone. From the 1st to the 10th it was unsettled and squally at Nancowry. Moderately strong south-west monsoon winds (on the average 50 per cent. stronger than the normal winds of the season) prevailed during the whole of this period. The sky was almost always overcast, and the prevailing cloud was nimbus. Heavy rain fell on the 6th and 7th. From the 10th the weather began to clear at Nancowry. At Port Blair, on the other hand, the weather became more showery, with increasing south-easterly or variable wind from the 1st to the 10th. The winds increased considerably in force from the 11th to the 13th, when they were almost double their normal strength. Weather was very unsettled and squally, and heavy rain fell on the 11th and 12th. These facts show that squally disturbed weather prevailed over a portion of the Bay, and that at this period, immediately before the beginning of the storm, the squally weather was first experienced in the south of the Bay and extended very slowly northwards from the 1st to the 12th, when the centre of the area of squally weather was probably in the latitude of Port Blair.

This squally weather was quite distinct from the cyclonic storm, although such weather very frequently precedes, and forms the first stage in the origin

of a cyclone. This is established by the fact that the meteorological information contained in the logs of vessels shows most clearly that there was no general cyclonic movement of the air before the evening of the 12th in the south or centre of the Bay. Thus the ship *Ireshope* in Lat. 17° 8′ N. and Long. 89° 45′E. on the 10th had fine weather and variable winds from south to west and calms with light occasional squalls. The *Udston* on the 11th in Lat. 11° 12′N., Long. 91° 6′ E., had light breezes from west-north-west to west-south-west, with clear and warm weather and a steady barometer, and on the 12th when she was in Lat. 12° 48′ N., Long. 90° 56′ E. at noon, or about 120 miles to the west-north-west of Port Blair, she experienced the following weather :—

"Early morning, wind changed to east for a short time with very heavy rain, then veered again to the west. At 8 A.M. rain ceased ; a light breeze from west-south-west. *Noon*, fresh winds with very unsettled appearance. *Afternoon and evening*, sharp squalls and heavy rain. *Midnight*, wind unsteady from west and north-west, squalls and heavy rain."

This vessel was at a short distance to the south of the area in which the cyclonic circulation and storm was generated during the next 24 hours. Her log is very interesting, as it proves most clearly that a period of unsettled weather and of variable winds, interrupted by squalls, increasing in strength, preceded the formation of the storm proper and formed in fact the preliminary stage.

History of the storm.—During the next 24 hours the transition took place from irregular, diffused, indefinite disturbance, characterized by squalls, occasional rain and variable unsteady winds, to a regular cyclonic movement on the large scale, with its characteristic features. The history of the storm proper hence begins with the 13th of October.

October 13th.—During the night of the 12th the weather became rapidly worse, and a definite cyclonic circulation was initiated, the centre of which at noon of the 13th was in about Lat. 16° 40′ N. and Long. 90° E. The *Udston* in Lat. 15° 17′ N., Long. 91° 6′ E., had west or west-south-west winds, with sharp squalls and heavy rain in the morning and in the evening a fresh south-south-east gale with squalls and drizzling rain. The ship *Chanticleer* in Lat. 17° 41′N., Long. 88° 36′ E., at noon had north-easterly winds with squalls and heavy rain. About 100 miles further north the *Ireshope* and *Patrie* had winds from north to north-east, fine weather and a smooth sea with occasional gusts during the morning. In the afternoon weather became squally and a violent squall passed over the *Patrie* at 2 P.M. The wind at 10 A.M. was steady from south-west at Nancowry and Port Blair. The barometer in that area during the day fell at first slowly, but in the afternoon and night more rapidly.

October 14th.—At noon of the 14th there was a small area of about 100 miles in diameter in which the barometer was from ·2″ to ·5″ below the normal height of the season, and in which the air was in rapid cyclonic motion and squalls of considerable intensity were occurring at frequent intervals. The centre of the disturbance was now marching in a north-north-westerly direction,

with a velocity of about 7 miles per hour, and its position at noon was in about Lat. 18° 50′ N. and Long. 88° 45′ E. The *Ireshope*, about 80 miles to the north-north-west of the centre at noon of the 14th, experienced the following weather :—

"*Morning.*—Increasing squalls, north-east winds. *Evening.*—Terrific squalls and heavy gale. *Midnight.*—Wind veered from north to north-west in a terrific squall."

The *Patrie* was about 60 miles further north. Her log states that in the morning the wind was from north-north-east and freshening. At noon she had heavy rain and continued squalls, in the afternoon very violent and continued squalls from the north-east, and at midnight the wind was from the east-north-east and blowing with hurricane force.

The *Udston* was advancing northwards up the east side of the Bay more rapidly than the cyclone, and was hence brought into the eastern quadrant during the afternoon. Her account of the weather is as follows :—*Morning.*—Overcast and dull, with hard squalls and rain. Wind from south-east. *Noon.*—Increasing gale, with terrific squalls. *Afternoon.*—Wind east, strong gale and heavy squalls. *Evening.*—Wind east, terrific gale, with a fearfully high sea.

The storm centre appears to have passed over the Arab ship *Fuzzel Kureem* on the morning of the 14th. Her position at noon of the 13th by observation was Lat. 17° 48′ N. and Long. 88° 33′ E. At that hour the weather was gusty, with showers of rain. The weather became rapidly worse during the evening and night. At 7 A.M. of the 14th she had the wind from the east and the jibboom was carried away. At 8 A.M. the wind shifted suddenly to the west, at 9 A.M. to south-west, and at 10 A.M. to south. The vessel during this period lost all her sails. In the afternoon the sea was very confused and made a clear breach over the vessel.

The various observations indicate that the storm on the 14th was of comparatively small extent, but that it had developed into a very intense, fierce, and dangerous cyclone. The inner storm area of considerable barometric depression and of hurricane winds was not more than about 50 miles in diameter. The outer storm area of strong winds, with more or less violent squalls, but of slight barometric depression, was not more than 200 to 250 miles in diameter. Outside of this area the weather was but slightly influenced. For example, the pilot vessel *Coleroon* had fine weather and a moderate north-east wind at 6 A.M. The floating light-vessel *Comet* (stationed at the Mutlah), the *Meteor*, stationed at the Eastern Channel, and the steamer *Sir John Lawrence*, passing down the river Hooghly had light to moderate airs and hot sultry weather until about 2 P.M., when squally cloudy weather, with winds increasing rapidly in force, set in. They were not more than 150 to 200 miles north of the storm centre at 2 P.M.

October 15th.—The observations of the 15th establish that the centre at

1 P.M. was in Lat. 21° N. and Long. 87° 45′ E. It had therefore advanced in a north-north-west direction during the previous 24 hours at an average rate of 7 miles per hour. The character of the weather in the storm area at this time is best understood by extracts from the logs of the vessels over which the inner storm area, or calm centre, passed during the day. The *Patrie* experienced the full weight of the cyclone on the morning and forenoon of the 15th. The wind was blowing with hurricane force in the early morning, and the sea rising very rapidly. The barometer fell from 29·65″ at midnight to 28·94″ at 5 A.M. The tempest was then raging with great fury and increased in violence until 9 A.M., when the barometer had fallen to 28·15″, after which the calm centre passed over the vessel. At the end of 15 minutes the storm commenced again to blow with greater violence than before. The wind continued to blow with hurricane force until 5 P.M., when the barometer had risen to 29·45″ and the weather began to moderate.

The storm centre passed over the pilot vessel *Cassandra* apparently very shortly after it left the *Patrie* behind in its advance northwards. She was five miles south-west of the Eastern Channel light-ship at 8 P.M. of the 14th, and was then tacking to the south-east. She appears, however, to have drifted considerably to the westward during the night. Between 7 and 8 A.M. of the 15th several of the sails were carried away. At 8-30 A.M. a strong gale was blowing with violent squalls from the east. At 10 A.M. the barometer had fallen to 27·90″ and a lull, lasting for about an hour, commenced. At 11 A.M. the wind shifted to the west and heavy squalls struck the vessel. At 11-15 A.M. the wind was blowing a hurricane. The barometer was rising rapidly at noon but the wind blew with tremendous force for upwards of two hours afterwards and did not begin to moderate until after 3 P.M.

The floating light-vessels at the Eastern Channel, Lower Gaspar, and Upper Gaspar stations felt the storm severely in the eastern quadrant and were all driven off their stations. The pilot vessel *Coleroon*, attempting to put to sea, was driven to the westward and caught right in the centre of the storm. She was at anchor at the pilot station near the Eastern Channel light-vessel on the 14th. The following description of the storm is taken from her log :—

"The weather was fine in the early morning, but at noon the sky became cloudy and the wind freshened. In the afternoon there were frequent squalls with heavy rain. The wind veered from north-east to east-north-east at 5 A.M. of the 15th, and was blowing a fresh gale. At 7 A.M. the wind was increasing fast and the sea rising. She was now put to sea under reefed foresail and staysail, but appears to have drifted to the westward and dragged her anchors for sometime previously under the force of the current and strong winds. The storm increased with unusual rapidity and blew with hurricane violence at 8 A.M. of the 15th, when the barometer had fallen to 29·52″. At 9 A.M. it was blowing a furious hurricane with blinding rain-drift, and a very heavy sea. The sails were now carried away and at 10-15 A.M. the vessel began to put her starboard rail under the water. At 11-30 A.M. (barometer at 28·95″) it was blowing a most furious hurricane and the sea commenced to make a breach over the vessel and to lay her over considerably so that it was necessary to cut away the main mast. At noon the barometer

had fallen to 27·88″, and the brig was entirely at the mercy of the storm and drifting to leeward. At 1 P.M. there was quite a sudden lull, which lasted for 45 minutes. At 1-15 P.M. there was almost a dead calm, the clouds cleared away, and the sun was faintly visible for a short time. The barometer had now fallen to 27·58″. At 1-45 P.M. the hurricane suddenly burst upon the vessel from west-south-west with more furious force than before the calm, burying the vessel under water. At 2-15 P.M. it was blowing a furious hurricane from west-south-west. The seas breaking on board in succession buried her port side in the water and nearly washed overboard all the seamen who were on the quarter-deck. The wind blew away the remains of the quarter-boat, and shortly after lifted the large boat from the top of the sheep-pen, tore it away from the gripes and extra lashings, and blew it away clear off the lee rail into the sea. From 2-30 P.M. to 4 P.M. it continued to blow a furious hurricane, the vessel being under no control, but drifting with the wind. At 4 P.M. the barometer had risen to 28·68″, and the weather began to improve."

The floating light-vessels the *Mermaid*, *Planet*, and *Meteor* were never nearer than about 30 miles from the centre. They experienced furious winds. Thus, the log of the *Mermaid* states that at 10-30 A.M. it was blowing a furious hurricane, the vessel driving and the rollers making a clear breach over the vessel, and at 3 P.M. it blew a terrific cyclone, with a frightful sea. The ship *Mistley Hall* was anchored in Saugor Roads on the 14th, waiting for a tug to take her up the river. The following are brief extracts from her log :—

"*15th.*—10 A.M., wind strong, east-north-east; barometer 29·59″. *Noon*, strong gale and hard squalls. 1 P.M., wind east, hard gale with tremendous gusts and torrents of rain. 2 P.M., gale increasing, barometer 29·35″. 3 P.M., wind east-south-east, hurricane with tremendous gusts and high seas breaking over us from stem to stern. 4 P.M., hurricane increasing from the south-east with tremendous gusts. 5 P.M., wind south-south-east, blowing very hard; barometer 29·05″, the lowest point reached. 6 P.M., terrific gusts, wind south : it was almost impossible to get along the decks. 7 P.M., gusts harder than ever; wind south by west. 8 P.M., hurricane continuing in a most extraordinary manner. 9 P.M., wind and weather moderating."

These extracts sufficiently illustrate the fury of the storm and the helplessness of mariners and ships when involved in the inner storm area of such a storm as the Midnapore cyclone.

The storm centre struck the coast near Contai shortly after 5 P.M., and then began to move first to north, then to north-north-east, and finally to north-east. It reached the coast just before the hour of low tide at the mouth of the Hooghly. The storm wave due to this cyclone hence only inundated a small portion of the Contai subdivision. The water at Diamond Harbour at 7 P.M. of the 15th, or about an hour before low water, was 16 feet above the level at the same hour of the preceding day and about 3 feet above the previous high tide. The effects of the storm wave were hence minimized to the greatest extent by the coincidence of the time of its arrival with the lowest state of the tide.

October 16th.—To complete the history of the cyclone the following brief account of its march through Bengal is given. The centre passed near Midnapore very shortly after midnight (0-30 A.M. of the 16th). The wind increased from early morning of the 15th, when a light north-east by east wind was blow-

ing. At 4 P.M. strong winds from north-east by north with heavy rain set in. At 6 P.M. it blew a gale from north. At 9 P.M. the wind was sweeping over the station in furious gusts, with torrents of rain. From 9 to 12 P.M. the force of the wind continued to increase, and the wind shifted slowly from north to north-west. At 1-30 A.M. it veered towards the west, and began to diminish rapidly in intensity, and the rain ceased shortly before daybreak of the 16th, at which time a moderately high wind was blowing from the west. During the storm ten inches of rain fell.

The most remarkable feature of the storm in the Balasore and Midnapore districts was the abruptness of the line of demarcation between the violent and destructive part of the hurricane, and of the moderate gale or outer storm area. The width of this western belt of destructive winds from the centre was about 25 miles, and it was near the western edge of this that the greatest destruction of life and property occurred. The loss of human life in the Midnapore district alone was 3,049, and of cattle 17,565, and was mainly due to falling trees and falling houses. Many were blown into tanks and drowned.

After leaving Midnapore the storm centre advanced in a north-north-east direction and passed over Burdwan at 5-30 A.M. of the 16th. At that station the wind on the night of the 15th was from north-east, and became more and more gusty. At 1 A.M. of the 16th it was blowing with considerable violence and at 3 A.M. the hurricane had reached its maximum strength. It blew with the utmost violence until between 5-30 A.M. and 6 A.M., when it decreased to a calm, which lasted until 6-30 A.M., when the wind recommenced to blow from the west, with gradually increasing force but with less violence than before the lull. The lowest reading of the barometer (corrected) was 28·44″ at 5-51 A.M. This was nearly an inch higher than the lowest reading on board the *Coleroon* and hence it is evident that the depression was filling up rapidly and the storm decreasing in violence. In the passage of the storm through the Burdwan district the winds were most violent, and the destruction of life and property greatest in the western quadrant, and near the outer western edge of the inner storm area, as we have seen was the case also in the Midnapore district.

The storm passed next through the Moorshedabad district in a north-easterly direction. The centre passed over Berhampore at about 2 P.M. of the 16th, or nine hours later than when it passed over Burdwan.

October 17th.—A large number of observations of various kinds from villeges in North Bengal serve to show that the storm was now becoming exhausted and loosing its true cyclonic character and probably breaking up into a number of separate eddies. The disturbance continued to advance in a north-east direction through North Bengal, but became more irregular and feeble, and finally died away as it approached the western scarp of the Garo Hills on the early morning of the 17th.

As already stated, there was no destructive storm wave connected with this

storm. The loss of life and property which occurred was due entirely to the violence of the winds; 3,392 human beings are reported to have perished in the storm, chiefly in the Midnapore district, but it was believed by the district officers at the time that this was far below the real estimate.

Brief summary of chief facts of the storm.—The following give the most important facts connected with the storm. It formed rapidly on the 12th and 13th, after a period of squally weather apparently lasting from the 1st to the 12th, in Lat. 15° 30′ N. and Long. 90° E., and advanced to the north-north-west by an approximately straight course. It reached the Bengal coast near Contai on the afternoon of the 14th, and then curved to north, and afterwards to north-north-east and north-east, passing into North-East Bengal, where it filled up on the evening of the 16th and early morning of the 17th.

Its path and velocity at different times are given in the following statement:—

Date.	Hour.	Position of Centre.		Velocity during interval since previous position.
12th	Noon	16° 40′ N. Lat.	90° E. Long.	7 miles per hour.
14th	"	18° 50′ N. "	88° 45′ E.	
15th	1 P.M.	21° N. "	87° 45′ E.	7 " "
16th	0-30 A.M.	Midnapore		9 " "
"	6 A.M.	Burdwan		10½ " "
"	2 P.M.	Berhampore		12 " "

A remarkable feature about the storm was the very slow rate at which it advanced during its northward march up the Bay, *viz.*, only 7 miles per hour. The velocity increased, as is frequently the case, after it reached land, but it was throughout a slow-moving storm. In both respects it resembled the still more remarkable False Point cyclone of September 1885.

The following gives the height of the barometer in the central calm area at different periods during the storm:—

Date.	Position of calm centre.	Reading of Barometer.	Observation where recorded.
14th	18°50′N. 88°45′E.	29·45″	On board the *Fuzzel Kureem.*
15th, 9 A.M.	20°45′N. 87°55′E.	28·15″	On board the Ship *Patrie* in the calm centre.
10 A.M.	Sandheads.	27·90″	On board the P. V. *Cassandra* in the calm centre.
1-15 P.M.	21° 0′N. 87°45′E.	27·58″	On board the P. V. *Coleroon* in the calm centre.
16th, 5-51 A.M.	Burdwan	28·44″	At Burdwan observatory in the calm centre.
1-15 P.M.	Berhampore	28·97″	At Berhampore observatory in the calm centre.

These observations are very interesting as showing how rapidly the de-

pression at the centre increased until it approached land, and how it filled up with almost equal rapidity after it reached land.

The following table gives a statement of the angle between the wind directions and the bearing of the storm centre for all the cases where the positions are known and the observations can be accepted as probably correct:—

Station or vessel.	Date.	Approximate distance from centre.	Approximate bearing of centre.	Wind direction.	Angle between wind and bearing of centre or bearing angle.	Weather.
		Miles.				
Saugor Island .	14th, 10 A.M. .	200	S.-S.-E.	N.-E.	112°	
	4 P.M. .	180	S. by E.	N.-E.	124°	
	10 P.M. .	145	S. by E.	N.-E.	124°	
	15th, 4 A.M. .	110	S.	N.-E.	135°	
	10 A.M. .	75	S.	N.-E.	135°	
	1 P.M. .	50	S.-S.-W.	E.	112°	
False Point .	14th, 10 A.M. .	180	S.-E.	N.-E.	90°	Strong wind.
	4 P.M. .	140	S.-E. by E.	N.-N.-E.	101°	Ditto.
	10 P.M. .	110	E.-S.-E.	N.-E.	68°	Ditto.
	15th, 4 A.M. .	85	E. by S.	N.-N.-W.	124°	Gale.
	10 A.M. .	70	E. by N.	N.-W.	124°	Do.
	4 P.M. .	100	N.-E.	W.	135°	Strong wind.
Ireshope .	14th, noon .	135	S.-S.-E.	N.-E.	112°	Position doubtful. Heavy rain and squalls.
Udston . .	" " .	100	W.-S.-W.	E.-S.-E. (doubtful)	135°	Terrific squalls.
Coleroon .	" " .	130	S. by E.	N.-E.	124°	Fresh breeze, cloudy, squally.
Comet . .	" " .	150	S.	N.-E.	135°	Squally; strong breeze.
Meteor . .	" 4 P.M. .	140	S.	E.-N.-E.	112°	Strong breeze.
Cassandra .	" 8 P.M. .	120	S.	N.-E.	135°	Strong wind.

The preceding table gives a large series of results for determining the bearing of the centre with respect to the wind. The Saugor Island series are very consistent, and show that the mean angle was very nearly 124°, or eleven points. The wind observations of the vessels show a wide range of angle as might be expected, but give almost the same angle on the average (119°) as the Saugor Island measurements.

The False Point observations are very remarkable. They show that in the earlier stages of the storm the wind was fairly steady at north-east and that the bearing angle, that is, the angle between the direction from which the wind comes and the bearing of the centre, was at that time very small, averaging for the three observations 86,° or about 8 points—but with the shift of wind to north-west, and its increase to a gale, the angle rapidly increased to 128°.

This behaviour of the north-east winds at False Point on the outskirts of a storm is not peculiar to that station, but extends over a portion of the north-

west angle of the Bay. The following extract from a letter sent by Master Pilot Mr. Elson to the Bengal Meteorological Reporter, describing the cyclonic storm of September 15th, 1888, states the fact from the standpoint of a practical man:—

"In this breeze *there was the same prolonged stay of the wind at N.-E.* that I have observed in the whole of this storm before it veered or hauled one way or the other, so as to furnish some clue as to which side of the storm path we were on. It would doubtless be very interesting to know the reason of this persistence of the winds in cyclones hanging thus at N.-E. in and off the Hooghly, but so it is, and up to the last I was in hopes the wind would go round 'north about,' and so give us a better chance of getting the wind on starboard beam and of escaping trouble and damage.

"As in the last heavy False Point cyclone the rear wind of this one never went to the westward of south at all with us in the N.-W. angle of the Bay, but remained persistently at S.-S.-E. and S.-E. by S., so that on the whole the characteristics of the several phenomena of both much resembled each other, excepting that the 1885 storm was more intense."

The subject has to a certain extent been dealt with in pages 123 to 128, and its consequences pointed out. A further examination of the point after additional evidence has been obtained is very desirable. There appears, however, to be little doubt that the north-east wind is the normal wind in the latter part of September, and that it is in the early stages of the approach of a cyclonic storm very little affected for some time, especially as the winds of indraught in the outskirts of the advancing storm are modified considerably by friction with the land, and it is only when the increased force due to the continued advance of the storm accumulates sufficiently that the shift of wind from north-east takes place rapidly, and then for the first time indicates approximately the bearing of the centre.

As to the fact and its practical bearing there can be no doubt. The north-east winds in the outskirts of cyclonic storms advancing to the north-west angle of the Bay are peculiarly treacherous and misleading. The fact, it may be added, furnishes a strong argument for the establishment of telegraphic communication to the light-vessels at the entrance of the Hooghly, as soon as it be possible to effect it.

THE FALSE POINT CYCLONE OF SEPTEMBER 19TH TO 23RD, 1885.

The False Point cyclone of 1885 is a very remarkable example of the small, but very intense and severe, cyclones which occasionally occur in the Bay. The lowest barometric reading (27·135″) taken at the False Point Light-house during the passage of the storm centre over it is lower than any previously recorded verified barometric reading at the sea level. It was, moreover, taken by a trained observer with a properly verified barometer at a land observatory, and may hence be accepted as quite accurate. The cyclone was in character a storm of the transition period—October to December—rather than of the rains.

It, however, occurred at least a fortnight earlier than any storm of similar intensity has been previously recorded, and is therefore in several respects unique.

Weather previous to the storm.—The storm began to form, so far as can be judged from the reports, on the afternoon of the 18th of September or the morning of the 19th. The weather for some days previously in Bengal and Northern India was such as accompanies a partial break of the rains. Rain had practically ceased to fall in Upper India. Skies were clear and winds variable in direction and unsteady, and indicated by their feebleness and irregularity of direction that they were no longer part of the general air movement of the south-west monsoon current proper. They were in fact very light local breezes or airs in an area beyond the limit for the time being of that circulation. This change of conditions gradually extended eastwards. Very little rain fell in South Bihar and Chota Nagpur for some days after the 9th or 10th. Rain continued to fall locally in the neighbourhood of the hills in North Bihar and in Bengal. A very small depression or whirl formed near the head of the Bay on the evening of the 14th, and advanced in a north-westerly direction and crossed the coast near Saugor Island on the afternoon of the 15th. It, however, filled up during the next 24 hours, and the weather over the whole of Bengal and Northern India on the morning of the 16th was such as is characteristic of a break of the rains.

Pressure was very uniform over the whole of Northern and Central India on the morning of the 16th. It was slightly higher in Arakan and South Pegu and at the Andamans, and hence probably over the adjacent Bay area. It was also considerably above the average pressure of the period. Winds were light, unsteady, and variable in Northern India. They were from the south-west in South Bengal, but further inland they were local, and very variable and irregular. No rain fell in Upper India, and practically none (that is, only a few local showers of no importance) in Bihar and Chota Nagpur. Moderate rain fell in Bengal, giving an average for the 24 hours preceding 6 P.M. of the 16th of about one-third of an inch. Skies cleared almost entirely in Bihar, Assam, and Bengal ; the south-easterly or easterly winds which had hitherto prevailed not only decreased in force, but were replaced over the whole of Bengal, except near the sea coast, by local brezees which were in many cases from opposite quarters at neighbouring observatories. The weather was fine, with occasional passing clouds. Temperature increased to some extent and the weather became, as is always the case during a break in the rains in September, sultry and oppressive.

We have now to consider the character of the weather in the Bay previously to the formation of the cyclone, so far as it can be illustrated from the meteorological information contained in the logs of ships. The weather in the Bay on the 16th appears to have been such as always obtains when the south-west monsoon is feeble. Pressure was lowest in the north of the Bay, and

highest in the south, but the differences or gradients were small in amount. Light west to south-west winds prevailed over its whole extent. The *Cuthona*, *Calcutta*, *Cynosure*, *Kunt Alfsson*, *Rollo*, *Blairgowrie*, *Saint Marnock*, *Goa*, and *Minnyhive* were all at or near the entrance to the Bay, and between Lat. 1° S. and 7° N. and in Longitudes varying from 82° to 99° E. at noon. They all experienced light winds, in no case exceeding 4 in force. The logs of the majority of those vessels record that the weather was clear and fine. Three report showers of rain, with slight squalls. Further north, the *Britannia* in Lat. 10° 19′ N. and Long. 86° 58′ E. had fine weather throughout the day. The *Brindisi* in Lat. 17° 49′ N. and Long. 84° 37′ E. had winds somewhat variable in direction and varying in force from light airs to a moderate breeze. The ship *Governor Wilmot* rounding the Alguada at noon had fine clear weather, smooth sea and light variable airs during the morning and afternoon, and a "very fine-looking sky" at 8 P.M. The *Lactura* near the head of the Bay had clear weather with passing clouds. The information indicates strongly that the weather was fine in every part of the Bay and that light monsoon winds generally prevailed. There was also no evidence of the commencement of squally weather, such as always precedes the formation of a cyclone.

September 17th.—The ship and land observations of the morning of the 17th show no important change in either the wind directions or the general character of the winds and weather. There were, however, signs of the commencement of squally weather. The *Minnyhive*, *Saint Marnock*, *Blairgowrie* and *Cuthona*, which were between Lat. 1° N. and 4° N. at the entrance of the Bay, had hot, sultry weather in the morning, and sharp squalls with heavy rain in the afternoon and evening. Further north the *Rollo* in Lat. 6° 46′ N. and Long. 87° 52′ E. and the *Cynosure* in Lat. 8° 09′ N. and Long. 87° 40′ E. and the *Kunt Alfsson* in Lat. 9° 49′ N. and Long. 85° 02′ E. had strong steady south-west winds during the day, with fine weather. These moderate to strong south-west breezes appear to have extended northwards as far as Lat. 13° or 14° N. The *Britannia* in Lat. 13° 02′ N. and Long. 87° 8′ E. had south-west winds of force 4 and fine fresh cloudy weather. Further north different weather prevailed. For example, the captain of the steam-ship *Governor Wilmot* in Lat. 15° 29′ N. and Long. 94° E. at noon reported that it was very hot and sultry in the morning and suffocatingly hot in the afternoon. The sea was very smooth and winds very light and variable (force 1). Several vessels contributed to the meteorological information of the north of the Bay on this day. The logs of these vessels describe the weather in such terms as "moderate breeze and fine," "fresh breeze, small clouds and fine weather," "fine clear weather with fresh breeze" and "weather fine and clear, sea smooth throughout." These observations for the 17th hence show that light to moderate monsoon winds prevailed as far north as about Lat. 14° N. Weather was as yet fine, although there were signs of the commencement of squally weather in the south

of the Bay. To the north of Lat. 14° N. light variable winds and hot, sultry oppressive weather prevailed.

September 18th.—The observations of the 18th show that there were as yet no indications of the formation of an area of local depression in the Bay. Over the greater part of the Bay there was no perceptible change in the weather. The south-west monsoon winds at and near the entrance of the Bay were increasing in strength and giving rise to more frequent and stronger squalls. The *Saint Marnock* had south south-west winds, force 4 to 6, and squally weather with heavy rain in Lat. 4° 26′ N. and Long. 84° 19′ E. The *Minnyhive*, in Lat. 3° 37′ N. and Long. 88° 26′ E., had hard squalls during the day, and the sky had a dirty wild-looking appearance. The *Rollo*, in Lat. 10° N. and the *Cynosure* in Lat. 11° 30′ N., had strong steady west-south-west winds. The *Britannia*, in Lat. 15° 50′ N. and Long. 87° 3′ E., had south-west winds of force 5 and much lightning with heavy showers. The ship *Governor Wilmot*, in Lat. 15° 37′ N. and Long. 93° 20′ E., had light, variable and very unsteady winds both in force and direction, and very hot, sultry and oppressive weather. A heavy bank of clouds was also observed during the afternoon and evening to the north-east.

The logs of a large number of vessels show that in the north of the Bay fine clear weather, with light south-westerly winds (but somewhat unsteady in character) still prevailed. The only part of the Bay area for which the information is somewhat scanty and imperfect is the Andaman Sea. The observations at Port Blair and Nancowry, and at the Burma and Tenasserim coast stations, as well as those taken on board ships in the Bay, shew most clearly that there was no cyclonic motion of the air in that part of the Bay. Squally weather with frequent heavy rain-showers prevailed over a large portion of the south and centre of the Bay, and the disturbed weather was extending northwards and invading the area of light variable winds and hot sultry weather to the west of the Pegu coast, so that a heavy bank of clouds had collected or formed apparently in the area over which the storm was generated during the next 24 hours. The observations at the Bay Islands confirm these statements to some extent. Thus, at Port Blair heavy rain was falling, skies were gloomy, and winds had increased very considerably in force. They were blowing from west or south-west, and were hence normal in direction, and such as precede and accompany the formation of a cyclone to the west of the Andamans. Moderate rain had also fallen at Nancowry. Little or no rain was falling in Burma.

The observations hence show that a considerable increase in the strength of the south-west monsoon winds had occurred over the south of the Bay. Weather also became unsettled and squally, and heavy rain began to fall in some parts of the south and centre of the Bay. So far as can be judged, this rainfall was heaviest at and near Port Blair, and it was in the sea area to the north of

the Andamans that the cyclonic storm originated and was generated during the next 24 hours.

Account of the storm.—*19th September.*—No change of importance occurred during the 24 hours preceding 10 A.M. of the 19th in Bengal or over the Bay north of Lat. 18° N. Calms or variable airs continued.

The weather in the Bay on the 19th is fully shown by the meteorological information extracted from the logs of the vessels. In the south of the Bay the south-west air current continued to increase in volume and intensity, and its northward advance over that area to the centre of the Bay (more especially the eastern half) was now accompanied with very unsettled, squally weather. The S. S. *Minnyhive*, in Lat. 6° 38′ N. and Long. 89° 12′ E., had westerly winds, and the captain states there was every indication of bad weather to the northward, the most significant being the appearance of dense heavy clouds from north-west to north-east above the horizon and frequent lightning. The S. S. *Cuthona*, in Lat. 10° N. and Long. 88° E., had moderate west-south-west winds, force 4. There was a bank of clouds to the north and frequent lightning. At sunset the sky was very red. The *Blairgowrie*, in Lat. 9° 18′ N. and Long. 87° 26′ E., had south-west winds of force 6 and a fresh monsoon. Skies were dull and heavy, and there was much lightning to the north and north-east. Three vessels, the *Rollo*, *Cynosure* and *Calcutta*, were all in about Long. 88° E. and between Lat. 12° and 14° N. All had west to west-south-west fresh breezes, and fine and hot weather. The only vessel near and within the area in which the storm was forming on this day was the ship *Governor Wilmot*. Her account shows the inception and increase of the storm during the day. She was in Lat. 14° 27′ N. and Long. 92° 8′ E. at noon, and proceeding slowly westwards on her course from Diamond Island to Calcutta. The following extracts, giving the weather experienced, are from her log :—

"*Early morning.*—North-west winds, force 6. Squally-looking, with smooth water. Constant rain. *Morning.*— Increasing breeze, with constant heavy rain. *Noon.*—Wind very unsteady ; constant rain. Very heavy rain at 4 P.M. Wind increased at 8 P.M. to force 8 from the west, and blew a whole gale."

The above account agrees with the general experience of cyclone generation in the Bay. Heavy continuous local rain in an area of light unsteady winds, fed by strong south-west monsoon winds prevailing to the south, is always the chief and most prominent feature. The barometer usually commences to fall simultaneously with the heavy rainfall. Winds are for some time afterwards unsteady, although increasing in force, and are interrupted by squalls, which increase in frequency and in intensity. After some time regular cyclonic motion of the air is established, which, if the rainfall continues and increases in amount, develops into rapid and violent cyclonic motion on the large scale over the storm area. This change in the present storm appears hence to have gone on continuously on the 19th in a small portion of the Bay to the south-south-

west of Diamond Island, and north of the Andamans, and on the afternoon and evening of the 19th the cyclonic storm was fully initiated. The observations taken at Diamond Island, about 170 miles to the north-east of the *Governor Wilmot's* position at noon, fully confirm the above, and show that the wind velocity there increased between 10 A.M. of the 18th from 10 miles an hour to an average of 25 miles an hour on the 19th and 20th. The storm was only in its initial stage on the evening of the 19th. It, however, gained very rapidly in intensity, and commenced to move slowly to the north-west in an almost straight course across the north of the Bay to False Point.

September 20th.—Winds were extremely light in Bengal, but southerly winds continued to prevail on the Bengal and Orissa coasts. Skies were partially clouded in Bengal but very little rain had fallen during the past 24 hours.

The logs of the ships furnish abundant evidence of the unusually rapid growth of the storm. They show that the centre at noon of the 20th was in Lat. 15° 30′ N. and Long. 91° 30′ E. or Long. 92° E. There were a large number of vessels to the south and west of the centre during the day. Their logs all record that unsettled squally weather, with gloomy threatening skies, extended over the greater part of the Bay south of Lat. 18° N. and east of Long. 86° E., but that strong winds (or winds exceeding 8 in force) were only experienced to a distance of 60 or 80 miles from the centre, except in the south quadrant, where they obtained over a large portion of the south of the Bay.

The following extracts from the logs of the three vessels nearest to the storm centre during the day will sufficiently illustrate its growth. The *Governor Wilmot* was nearest to the centre in the morning and at a distance of 60 miles to the north-north-east at noon. Her log for the day is as follows :—

"4 A.M.—Wind west-north-west, force 10. 8 A.M.—Wind west, force 11, blowing a hurricane. Sky black, with thick low clouds; constant heavy rain. Barometer fell rapidly during the morning and stood at noon at 29·5". The sky was very thick and black at noon, so that it was more like night than day. 4 P.M.—Wind south-west, force 11. 6 P.M.—Weather began to improve."

The changes are evidently explicable by the rapid growth of the storm and its north-westerly advance away from the vessel.

The *Cynosure* was about 180 miles to the west by south at noon. She had, at 8 A.M., moderate breezes and cloudy skies; at noon light airs and calms, thunder and lightning; and in the afternoon squalls and heavy rain.

The *Canara*, about 200 miles to the north-north-west at noon, and advancing to Calcutta had fine clear weather from noon to 8 P.M., and moderate breezes, passing clouds and a smooth sea from 8 P.M., to midnight.

These observations prove conclusively that the storm area of this cyclone was of small extent, and that outside this storm area the winds and sea were very slightly influenced as yet by the disturbance.

September 21st.—The various observations indicate that the centre at 10 A.M. of the 21st was in Lat. 17° 30′ N. and Long. 89° 30′ E. or 89° 45′ E., so

that it had travelled 180 miles to the north-west during the previous 24 hours. In Bengal skies were much less clouded than they had been previously.

The storm moved more rapidly during the afternoon and night of the 21st, and reached the Orissa coast early on the morning of the 22nd. It apparently grew rapidly in intensity during the day, but the inner storm area was not much enlarged, so that it continued to present the same features as on the 20th of a small area of not more than 50 or 60 miles in diameter in which the winds raged with hurricane force, whilst beyond it they decreased rapidly in intensity, and at distances of 80 to 100 miles from the storm centre were comparatively feeble.

The following gives extracts from the logs of those ships which were involved in the storm during the 21st. The first was the *Calcutta*, which was about 50 miles to the south of the centre at noon of the 21st. The account in her log is brief:—

"Winds changed gradually from north-west to west by south, and then to south-south-west, and finally to south by east. Terrific squalls at noon with a regular downpour of rain. The sea in the evening seemed to come from all quarters."

This vessel passed from the south-west to the southern quadrant, but was never nearer the centre than about 50 miles.

The schooner *Kunt Alfsson* was also on the outer verge of the inner storm area during the morning and afternoon, and in the same quadrants (*i.e.*, the western and southern) as the previous vessel. Her log states:—

"In the early morning, it was calm until 3 A.M., when the wind began to blow from north and afterwards shifted to north-west. It freshened to a stiff breeze with squalls and rain before noon. During the afternoon the wind became stronger from north-west, with frequent squalls and an immense quantity of rain. Before 4 P.M. the wind was blowing a terrific gale. At 4 P.M. wind was from west, and at 7 P.M. from west-south-west. The water was discoloured and appeared to be black. We sounded, but obtained no bottom with 90 fathoms. Rain poured down continually during the afternoon in immense quantities without ceasing. The gale blew in terrific gusts, and the sky was intensely black, the sea very turbulent and high."

The log does not indicate at what time she was nearest to the centre nor the height of the barometer, and hence the remarks are chiefly valuable as evidence of the excessive condensation of aqueous vapour and precipitation of rain which was the chief cause of the concentration and violence of the storm.

The *Quang Tung* left the Sandheads on the 19th for the Andaman Islands and her course took her directly through the storm area. She was nearest to the centre at 4 P.M. of the 21st, when she was about 70 or 80 miles to the north of the centre and in the outer storm area. The following extracts are from her log of that day:—

"4 A.M.—Sea smooth. 8 A.M.—Wind east-north-east, force 5. Moderate north-east sea and swell. 9-45 A.M.—Wind and sea rapidly increasing. Very heavy south-east sea. *Noon.*—Wind east by south, force 8. Very heavy sea. 4 P.M.—Wind east by south, force 9. 8 P.M.—Very hard squalls from the eastward."

The next vessel in order of time was the *Clan Mackintosh*. She was proceeding northwards to the mouth of the Hooghly, and was, hence, advanc-

ing across the line of march of the storm during the day. The following account is taken from her log :—

"*September 21st*, 4 A.M.—Light variable winds; sea smooth. 8 A.M.—Freshening breeze, with dark gloomy weather. 8·30 A.M.—Violent squalls and heavy rain. *Noon.*—Strong breeze (north) with heavy squalls of wind and rain. *Afternoon.*—Wind (north) increased. Ran to south-west to avoid cyclone. 10 P.M.—Wind shifted to north-north-west. *Midnight.*—Strong gale, with terrific squalls and torrents of rain. Wind blowing at times with hurricane force. Wild confused sea. *September 22nd*, 2 A.M.—Wind north-west, blowing at times with hurricane force. Torrents of rain; vivid lightning. 5 A.M.—Wind moderating and sea less confused."

September 22nd.—The tug steamer *Britannia* was advancing slowly to the mouth of the Hooghly and was off the Orissa coast on the 21st. She was hence right in the track of the cyclone and experienced its full weight on the night of the 21st. The following account is extracted from her log:—

"*21st*, 4 A.M.—Wind east-north-east, force 3. *Noon.*—Barometer 29·6", wind north-north-east, force 6. 4 P.M.—Wind north-east, force 6. From noon the wind increased in force, and at 1 A.M. of the 22nd was blowing with hurricane force. Barometer stood at 28·2" (corrected reading 28·16") from 1 A.M. to 3 A.M., when there was half an hour of calm weather. The wind then came down from the west (backing to south-west) with terrible force until 6 A.M. when it began to moderate. During the storm the fore and main top-gallant masts and yards were lost, and the whole suit of sails blown away from the yards, except the main sail and jib."

The *Booldana* on the 21st was lying off False Point at the anchorage ground. The following account of the storm is taken from her log :—

"At 4 P.M. wind was from east-north-east, and there was a heavy sea running with dirty squally weather. At 8 P.M. wind north-east, force 9. Sea increasing. At midnight strong gale, with *very hard dry* squalls. 2 A.M. of the 22nd.—Gale increasing with slight rain. 3·30 A.M.—Heavy squall; wind blowing a very heavy gale. 4 A.M.—Barometer began to fall very rapidly, and wind and rain increased. 5 A.M.—Wind north-east. 6·15 A.M.—The weather cleared up with clear sky overhead, but round the horizon all dark. 7 A.M.—Barometer at its lowest 27·4" (uncorrected). The gale came down from the opposite quarter (south-west), making it impossible to stand on deck without holding on. 9·45 A.M.—Force of the gale gradually abating. *Noon*—.Fresh squalls from south-west."

The weather in other parts of the Bay was more or less squally with strongish winds and a high sea. The sea was especially high in the shallow water at the head of the Bay. The following brief quotations will suffice to describe it:—

The *Favonius*, in Lat. 16° N. and Long. 85½° E., at noon, had very high seas and very cloudy weather. The sea was running from all directions. The ship *Governor Wilmot*, in Lat. 17° 40′ N. and Long. 90° E., at noon, had an awful sea from north-west at 4 P.M. The barque *Rollo*, in Lat. 18° 17′ N. and Long. 89° E., had a high confused sea, and a strong gale and rain. The pilot vessel *Coleroon* was at anchor at the Sandheads. Her chains parted at 6·30 A.M. of the 22nd, owing to the tremendous sea running.

The lighthouse at False Point is situated about 7 miles to the south-south-west of the anchorage ground in the harbour. The calm area passed over

it very shortly after it reached the *Booldana.* The following is the account of the weather, as given by the lighthouse-keeper :—

"The weather began to assume a threatening appearance between 4 and 5 P.M. of the 21st when the wind was from the north-east, and blowing in squalls with an overcast sky, and heavy banks of clouds rolling up from the north-east. The weather continued the same, with the wind increasing in force and squalls more frequent until between 1 A.M. and 2 A.M. of the 22nd, when it blew a gale. At 4 A.M. the wind had increased to a hurricane, and the squalls were most terrific, with blinding sheets of rain. The wind was still from the north-east, and the barometer falling rapidly. At 6·30 A.M. the wind hauled to the north-west, and continued to blow a hurricane for a few minutes, when it suddenly lulled and became almost calm. At 6·50 A.M. the wind came down with redoubled force from the west-south-west, the gusts being most terrific. From 7 A.M. to 10 A.M. the barometer rose rapidly and the wind gradually moderated to a gale, and at noon it blew a fresh breeze from the south-west, with squalls."

The storm advanced in a north-westerly direction during the day across North Orissa and Chota Nagpur, and gave very heavy rain in Orissa. The Collector of Balasore reported that the rainfall on the Orissa hills was extraordinarily heavy, and caused high floods in all the rivers in his district, which inundated all the low-lying lands. Strong southerly winds continued over the whole of the centre and north of the Bay during the day.

September 23rd.—The centre passed through the districts of Ranchi and Hazaribagh on the early morning of the 23rd, and was between Dehri and Hazaribagh at 10 A.M. The storm had, however, almost filled up by this time, and it existed for some hours longer as a diffused disturbance which advanced northwards into North Bihar, where it finally broke up completely on the morning of the 24th. The strongest winds in the Bay on that day were only of force 3-4, so that the weather in the Bay had reverted to its normal character at the end of September.

The storm wave.—The storm wave inundated the whole of the low land in the neighbourhood of the False Point Harbour. High water was due at about 8 A.M., so that the storm wave which accompanied the central depression and calm area preceded the tidal wave by about two hours. The storm wave came up at 6-20 A.M. and swept over False Point Harbour, destroying all the houses ashore. It passed over Jumbo at the entrance to the canal, and then rolled in one wide unbroken wave in a north-easterly direction over Kaldeep and Kerara, submerging villages and carrying away before it, with irresistible force, houses, cattle, human beings, &c. The trees were rendered leafless and scorched as if by the blast of a furnace. The measured height of the wave above mean sea level was 22 feet at False Point and 21 feet at Jumbo. The effect of the tidal wave was suddenly to create a sufficient depth of water all over the harbour sufficient to float large steamers. The *Booldana* was carried over shoals where there is ordinarily at high tide only a few feet of water.

Brief summary of chief facts of the storm.—The preceding account has hence shown that the False Point cyclone was generated in an area of calms and light unsteady winds to the south-west of Diamond Island on the 17th and

18th. Excessive rain fell in this area, and the storm developed with unusual rapidity on the 19th in about Lat. 15° N. and Long. 92½° E. It was fully formed on the afternoon of the 19th and marched in a north-westerly direction. The centre advanced rapidly without change of course to the Orissa coast, which it reached about 6 A.M. on the 22nd. The central calm area passed over the lighthouse, and lasted for half an hour. The storm advanced across Cuttack and the Orissa hills, but decreased very rapidly from this period. It gave a deluge of rain to those hills, and thence passed through Chota Nagpur on the 22nd and Bihar on the 23rd, and died out in North Bihar on the morning of the 24th, after having given heavy rain in Chota Nagpur and moderately heavy rain in Bihar.

The following table gives the positions of the storm centre at different hours:—

Date.	Position of the centre.	Motion during previous interval.	Average rate of motion.
20th—10 A.M. . .	Lat. 15°30′ N. Long. 91° 30′ E.		
21st—10 A.M. . .	Lat. 17° 30′ N. Long. 89° 30′ E.	180 miles in previous 24 hours.	7½ miles per hour.
5 P.M. . .	Lat. 18 N. Long. 88° 20′ E.	92 miles „ .	13 „ „
22nd—6-30 A.M., 6-50 A.M.	False Point Lighthouse	170 „ „ .	12½ „ „
23rd—10 A.M. . .	Near Dehri . .	320 „ „ .	13 „ „

Hence, during the latter part of its existence it moved very uniformly, and at a rate averaging 13 miles per hour.

The following gives the readings of the barometer in or near the storm centre at different hours:—

Date.	Position of calm centre.	Corrected barometric reading.	Where observed.
21st September, noon .	Lat. 17° 30′ N., Long. 89° 15′ E.	29·26″	On board the *Calcutta*, a little to the south of the storm centre.
„ 5 P.M.	Lat. 18° 40′ N., Long. 88° 20′ E.	28·79″	On board the *Kunt Alfsson*, a little to the south of the centre.
22nd, 3 A.M. . . .	45 miles east-south-east of False Point.	28·16″	On board the *Britannia*, 45 miles east-south-east of False Point in the calm centre
„ 6-30 A.M. . .	False Point . .	27·135″	Observed at the Lighthouse during the passage of the calm centre.
23rd, 10 A.M. . .	Dehri . . .	29·543″	At observatory to the west of the centre.

These data show how rapidly the storm developed in intensity on the afternoon and night of the 21st and early morning of the 22nd. The barometric depression increased an inch at the centre (if the data, which appear to be thoroughly trustworthy, be accepted) between 3 A.M. and 6 A.M. on the early morning of the 22nd when approaching the Orissa coast. The storm apparently filled up with equal rapidity after reaching land.

The following table gives the distances at which winds of intensity 8 and upwards were observed at sea:—

Date.	Ship.	Bearing and distance of centre.	Force of wind.
20th, noon .	*Governor Wilmot* . .	90 miles north-west . .	11
„ 8 P.M. .	*Cuthona*	300 „ north-east . .	11
21st, 4 A.M. .	*Governor Wilmot* . .	225 „ north-west . .	8
„ noon .	*Blairgowrie* . . .	110 „ north . . .	8
„ 4 P.M. .	*Cuthona*	250 „ north-north-east .	10
„ 4 P.M. .	*Quang Tung* . . .	180 „ south . . .	9
„ midnight .	*Britannia* . . .	260 „ south-east by south	10
22nd, 4 A.M. .	*Saint Marnock* . .	340 „ north-north-west .	8
„ 4 A.M. .	*Booldana* . . .	Near centre . . .	11
„ noon .	*Quang Tung* . . .	250 miles west-north-west.	8

The following data give the angles between the direction of the wind at Saugor Island and the bearing of the centre during the storm:—

Time.	Wind direction.	Distance and bearing of centre.	Bearing angle.	Weather.
10 A.M., *21st* . . .	N.-E. by E.	300 miles to S.-S.-E. .	101° . .	Squally.
2 P.M., „ . . .	E.-N.-E.	250 miles to S.-S.-E. .	90° . .	„
6 P.M., „ . . .	E.-N.-E.	200 miles to S. by E. .	101° . .	„
10 P.M., „ . . .	E.-N.-E.	155 miles to S. . . .	112° . .	„
2 A.M., *22nd* . .	E. by N.	130 miles to S.-S.-W. .	124° . .	Gale.
6 A.M. „ . .	E. by S.	120 miles to S.-W. . .	124° . .	Severe gale.

They give an average of 109°, or 10 points, and show a considerable amount of variation, *viz.*, from 90° to 124°, or 34°, which is not much beyond the limits of

variation that might be expected from the rough method of measurement of wind direction employed, and the position of the observatory in the north-west angle of the Bay.

The wind at False Point *remained steady at north-east during the whole period of approach of this storm until within a few minutes before the calm area reached the station when it shifted suddenly to north-west.* As the storm advanced in a north-westerly direction to False Point, the angle between the wind direction and centre was hence throughout 90°. This is another example of the peculiar wind relations which appear to obtain at False Point and probably over the adjacent portion of the Bay.

The following table gives data for ships the positions of which are known to be approximately correct:—

Date.	Wind direction.	Approximate bearing and distance of centre.	Bearing angle.	Weather.
Canara, 20th, noon .	E.-N.-E. .	160 miles S. . . .	112° . .	Squally.
Blairgowrie, 21st noon	S.-W. .	110 „ N. . . .	135° . .	Fresh gale.
Britannia „ .	N.-N.-E. .	210 „ S.-E. . . .	112° . .	Gale.
Rollo „ .	N.-W. by W.	150 „ N.-E. . .	101° . .	„
Governor Wilmot .	S.-S.-W. .	230 „ N.-W. . .	112° . .	Squally.

The data give a mean angle of 114°, or very nearly ten points.

THE AKYAB CYCLONE OF MAY 1884.

This small cyclone is an example of a class of storms which are of almost annual occurrence. These storms are formed in the month of May, when the south-west monsoon current proper enters and advances up the Bay of Bengal.

The storms which form in this manner during the first fortnight of May usually advance to the Madras coast. Those which originate in the latter part of May or beginning of June generally move north-west to the Bengal or Orissa coast, but under very exceptional circumstances they advance northwards and then recurve to north-north-east or north-east and strike the Arakan or Chittagong coast.

The present storm, although it was generated during the first fortnight of May, marched northwards and then recurved and struck the Arakan coast.

Weather previous to the formation of the cyclonic storm.—When the advancing humid mass of air of the south-west monsoon current enters and advances over the south of the Bay (where the air was previously in an almost quiescent state) forcing its way forward, there is much internal commotion. Squalls are of frequent occurrence, and rain falls in large amounts.

And when these winds and squally weather have marched some little distance up the Bay, as far as Lat. 10° or 11° N., the rainfall and squalls frequently become intense, and the disturbance thus set up gradually becomes more localised and concentrated, and occasionally develops into a cyclonic storm. If these actions take place early in May, the storm so formed usually marches to the Madras coast in a west-north-west direction. The present storm is an example of this class of storms which form during the early advance of the south-west monsoon air current up the Bay. It, however, adopted a very unusual course, and marched first north, and then curved round to north-east and struck the Arakan coast near Akyab.

The history of the cyclone commences on the 11th of May, when the weather in the Bay was such as is described above. South-west winds of force 3 to 4 were blowing at the head of the Bay, and the weather was fine but hazy. Light variable winds and calms prevailed over the whole of the Bay between Lat. 20° N. and Lat. 6° N. Over and near the Equator the weather was unsettled and squally. Skies were overcast, and heavy showers of rain were falling at intervals. The log of the ship *Belfast* of Liverpool, which had made a rapid and favourable passage through the south-east trades, and was in Lat. 5°3′ S. and Long. 87° E. at noon on the 11th, states that she had steady south-east winds until 7 P.M. of that day, when a squall from west-north-west passed over the vessel. The weather at Galle and Colombo was fine, with passing clouds, and winds were light. Hence the character of the weather in the Bay on that day is evident. Over a narrow belt near the north and west coasts there were strongish winds blowing from the sea to the land. Over the whole of the Bay proper, winds were very light and variable, weather sultry, and the sea smooth, and there was no sign or indication of stormy or squally weather.

May 12th.—During the next 24 hours no change occurred except in the extreme south of the Bay. The *Kalima*, in Lat. 3° N. and Long. 84° E., had violent south-west squalls and heavy rain. The *Udston*, 40 miles further north, had hard west north-west squalls and heavy rain. The *Bhundara*, in Lat. 8° 20′ N. and Long. 82° 30′ E., at noon, experienced light to moderate west-north-west winds and showery weather. Further north, from Lat. 10° N. to Lat. 18° N., light variable winds and clear fine weather continued. The *Iolanthe*, in Lat. 16° N. and Long. 93° E., at noon, had light variable winds and a slight swell from south-south-east. There were a few light detached clouds about, but with that exception skies were clear. The light-ships at the entrance to the Hooghly had fine weather and a smooth sea. Hence the only change in the weather was the advance of squally weather as far north as Lat. 5° or 6° N. In this area the squalls were more severe than on the 11th, and rain was falling more or less steadily and continuously. This advance of a humid, squally current of air is

further confirmed by the change in the weather which had taken place during the previous 24 hours in Ceylon. The skies clouded over in that island, winds strengthened, and heavy rain began to fall on the afternoon of the 11th. Colombo, for example, received 3·42 inches during the day.

May 13th.—The humid current in the south of the Bay continued steadily to advance northwards, and at noon of the 13th had reached Lat. 9° or 10° N. The winds increased in strength, squalls were more frequent and severe and the rainfall more continuous and intense. The *Udston*, in Lat. 7° N. and Long. 85° 47′ E., had hard squalls during the day. The *Kalima*, in Lat. 6° 20′ N. and Long 84° 40′ E., at noon, experienced variable winds, violent squalls and constant rain during the day. The steam-ship *Bhundara* was, as on the previous day, a little in advance of the area of squally weather, and was travelling northwards at nearly the same rate as the advancing south-west monsoon current. She was at noon in Lat. 11°55′E. and 83°56′E. and had light variable winds and calms with fine weather. Skies were overcast, but she received no rain. Further north the ship *Iolanthe*, which was advancing northwards to Calcutta in the neighbourhood of the Burma coast (near Cape Negrais), had light airs and calms, and had made only 10 miles during the previous 24 hours. Hitherto the squally unsettled weather had been confined to that part of the Bay of Bengal in the immediate neighbourhood of the Equator in which cyclonic storms never occur. But, with the northward extension of the strong, humid south-west monsoon winds, the accompanying atmospheric disturbance reached a portion of the Bay where under favourable conditions squally weather may develop into a cyclonic storm as on the present occasion.

History of the cyclonic storm.—*May 14th.*—This change occurred, as will now be seen, during the next 24 hours. A largish fall of the barometer had taken place during the previous night at Port Blair and Nancowry. The winds had shifted during the previous 48 hours from south-south-east to south-south-west at Nancowry, and from north-west to south-east at Port Blair, and increased very considerably in strength and were nearly three times as powerful on the morning of the 14th as on the 13th. The wind directions had shifted on the west coast of the Bay south of Vizagapatam round from south-west to north-east and north-west. Strong westerly winds were blowing steadily at the Ceylon ports. These winds show clearly that a cyclonic circulation was now established over the centre of the Bay, and the history of the cyclone hence dates properly from this day.

Heavy rain continued to fall in Ceylon, and moderately heavy rain set in at Port Blair and Nancowry, which were now receiving their first showers from the advance of south-west winds. The wind directions and barometric observations recorded on board ships, as well as at the coast stations, show that a barometric depression, the centre of which was at noon in about Lat. 11° N. and Long. 89½° E., had begun to form, over which the air was moving cyclo-

nically. The logs of the vessels in the Bay indicate that the weather in the south of the Bay was becoming more and more unsettled and threatening, the squalls more severe, and the winds cyclonic in intensity, as well as in direction.

The *Belfast*, in Lat. 1° 10′ N. and Long. 88° 31′ E., at noon, had hard squalls and increasing winds. The *Kalima*, in Lat. 8° 32′ N. and Long. 84° 33′ E., experienced constant rain and violent squalls. The *Udston*, in Lat. 10° N. and Long. 86° 49′ E., had winds of force 9 from the north-west, with violent squalls at frequent intervals and a high sea. The *Bhundara*, which had advanced to Lat. 15° 46′ N. and Long. 84° 45′ E., had light variable breezes and fine weather during the day, so that she was, as hitherto, just beyond the area of disturbance and unsettled weather. The steam-ship *Brindisi* in the same latitude, and 100 miles further west, had clear skies and a calm sea. The *Iolanthe*, in Lat. 16° 27′ N. and Long. 92° E., had hazy weather and light east-south-east winds, but a south-east swell (evidently due to the cyclone) began to roll up. At the head of the Bay the weather was fine but hazy, and the sea calm.

Hence we see that the disturbance which was now developing into a cyclonic storm had commenced as squally weather and heavy rain near the Equator, and that it had extended northwards and increased in severity and violence, and when it had advanced beyond Lat. 8° N. or 9° N. it had changed in character. Hitherto there had been no centre of action. The weather had been squally, with heavy rain showers, but the winds had not shown regular and continued convergence to a centre of indraught. During the previous 24 hours a definite centre, about which the actions were taking place, had been established. The barometer fell most rapidly at and near it, rain was heaviest in its neighbourhood, squalls were very violent, and the winds between the squalls not only increased in force, but showed that indraught to a centre which is the characteristic of a cyclonic circulation and storm.

May 15th.—We have now to follow the march of this cyclonic whirl which had developed out of the squally weather in the south of the Bay. Strong, steady south-westerly winds were blowing at the Ceylon ports, but little or no rain fell in Ceylon during this day. In the east of the Bay very strong winds continued to prevail at Nancowry and Port Blair, and had extended during the previous 24 hours to Diamond Island, where rain had also commenced to fall. Winds had also strengthened on the west coast of the Bay, and were already above their usual force in May. The observations extracted from the logs of the vessels show that the centre of the cyclonic storm was at noon in Lat. 13° N. and Long. 90° E., so that it had advanced about 150 miles during the previous 24 hours. The *Belfast* of Liverpool, in Lat. 3° 49′ N. and Long. 88° 33′ E., at noon, had south-west winds of force 8, and huge seas from west and west-south-west, but no rain. The *Kalima* and *Udston* were nearest to the centre and experienced very rough weather. The *Kalima*, in Lat. 11° N. and Long. 85° 50′ E. at noon, had frequent squalls, during which the winds

blew with great force, and intervals of calm. The *Udston*, farther east in Lat. 11° 18″ N. and Long. 87° 30′ E., had terrific squalls with heavy forked lightning and a high cross sea. Squally weather and a disturbed sea appear to have extended to about 250 miles north of the centre of the storm, or to Lat. 17° N., at noon, as the *Pemba* in Lat. 15° 33′ N. had a strong gale, and the *Iolanthe* in Lat. 17° 20′ N. had steady winds, a high sea and threatening weather. The *Bhundara*, which was in Lat. 19° 16′ N. and Long. 88° E., at noon, had light airs and hazy weather, and the *Brindisi*, in Lat. 19° N. and Long. 86° 17′ E., fine clear weather and a calm sea. The *Comet*, *Meteor*, and *Star* Floating Light vessels off the mouth of the Hooghly all reported fine and hazy weather smooth sea, and light winds.

May 16th.—The observations of the 16th show that the disturbance had now become a violent and dangerous cyclonic storm. The storm area had not as yet extended to the Bengal and Orissa coasts, as light southerly winds continued to blow during the day at Saugor Island and False Point, and the weather was fine, with passing clouds and slight sea. The winds at Akyab had backed from south-east to east with the northward advance of the cyclone, but were as yet very light Skies had clouded over on the Arakan coast, and light drizzling rain was falling.

The various observations, when charted, establish that the centre of the storm was at noon of the 16th in Lat. 15° 40′ N. and Long. 90° 45′ E., and was travelling northwards at a rate of nearly nine miles an hour. It was at that time about 300 miles due west of Diamond Island and Cape Negrais. Very strong winds prevailed over the Bay to the south of the depression and storm area, and winds of hurricane force in the inner storm area, whilst further north they diminished rapidly in strength and at the head of the Bay were very light, and almost the same in direction on the morning of the 16th, as if the storm had not existed.

The ship *Belfast* of Liverpool, in Lat. 5° 45′ N. and Long. 87° 37′ E., at noon, experienced south-west winds of force 7 to 8 during the day, with fine weather and a very high sea. The *Udston* whose position at noon is stated in the log to have been in Lat. 11° 54′ N. and Long. 87°3′ E., or upwards of 300 miles to the south of the centre, experienced very stormy weather. The wind during the day blew from all points of the compass with terrific force (varying from 10 to 12). Heavy rain fell throughout the day, and the sea ran very high. The steam-ship *Pemba*, which left Rangoon for Calcutta on the afternoon of the 14th, rounded Cape Negrais and passed into the Bay of Bengal on the evening of the 15th. She was in Lat. 17° 10′ N. and Long. 91°17′ E., at noon, and had furious squalls during the afternoon, and weather became rapidly worse, so that after 8 P.M. it blew a hurricane, with a high confused sea and blinding rain.

The weather to the north and north-west was in remarkable contrast to

that in the centre and south of the Bay. The *Bhundara*, anchored off Puri, had light airs. The *City of Khios*, in Lat. 16°46′ N. and Long. 86°10′ E., at noon, had light north winds of force 2 during the whole day. Skies were clouded, but the weather was fine throughout. The *Clan Mackintosh*, in Lat. 15°11′ N. and Long. 82°29′ E., was, like the *City of Khios*, advancing northwards at about the same rate as the storm. She experienced very hot and sultry weather, with overcast skies and light winds.

Hence, as hitherto, the cyclonic storm was a small feature in front of a large area of very strong humid southerly winds. The storm had marched northwards with the northward extension of the area of southerly winds and was apparently impelled or carried forward by these winds. It was influencing the weather and winds over the greater part of the north of the Bay, but it was as an intruding element, and its influence was not felt to any marked extent at distances greater than 150 to 200 miles to the north and west of the storm centre.

May 17th.—The character of the storm and the path of the centre on the evening of the 16th and morning of the 17th are known accurately from series of observations taken on board the *Rajputana* and *Pemba*, steamers on the Burma lines of the British India Steam Navigation Company. The *Rajputana* was proceeding from Calcutta to Rangoon. She passed out of the Hooghly on the afternoon of the 15th. The weather was then fine, with light easterly winds. Her direct path lay across the front of the cyclone. As she advanced the weather changed and became very threatening. The winds increased rapidly in force and hauled round, and at last, when the vessel was not more than 150 miles from the storm centre, the barometer began to fall slowly.

The position and direction of line of march of the cyclone which the steamer was now evidently approaching were accurately judged, and the captain judiciously changed his course from south-east to south-west for some hours, and thus passed round the cyclone in its westerly and southerly quadrants. The *Rajputana* was nearest to the centre at 4 A.M. of the 17th, when it was in Lat. 17° 50′ N. and Long. 91° 20′ E., and about 95 miles to the east of the vessel. She experienced from 1 A.M. until 8 A.M. of the 17th a very heavy gale with terrific squalls. As she proceeded eastwards to the south of the Burma coast, the weather improved rapidly.

The *Pemba* left Rangoon on the afternoon of the 14th for Calingapatam, a port on the opposite coast of the Bay, between Vizagapatam and Gopalpore. She passed the Alguada Reef at about mid-day of the 15th, and then proceeded almost due west across the Bay. This brought her in front of the storm on the 16th. The weather became rapidly worse on the afternoon and evening of the 15th. A strong gale from north-east, force 10, with heavy rain, was blowing at 7 A.M. of the 16th. It blew a strong gale with furious squalls after noon, and

the course of the vessel was then changed to north under easy steam. The barometer fell rapidly during the day, and before 8 P.M. it blew a hurricane with a high confused sea and blinding rain. The barometer was lowest at 2 A.M. of the 17th when the corrected reading was 29·09″. The *Pemba* was at that hour about 20 miles to the west of the centre. It is hence probable that the barometric height at the centre of the storm was not at that time lower than 28·9″. The weather began to moderate as the storm centre advanced northwards from the steamer, but strong winds and violent squalls were experienced untill the evening of the 17th.

The various observations (especially those taken on board the *Rajputana*) indicate that the centre, which had hitherto moved in a northerly direction, began to curve to east on the afternoon and evening of the 16th. This motion to the east of north became more marked on the 17th. There were no ships in the immediate neighbourhood of the centre of the storm on the 17th. The various observations show that it was approximately in Lat. 19° N. and Long. 91¾° E., at noon. It had therefore advanced about 240 miles during the previous 24 hours, *i.e.*, at the rate of 10 miles per hour.

The character of the weather in the Bay is clearly indicated by the ship observations. The ship *Udston*, in Lat. 14° 24′ N. and Long. 86° 44′ E., at noon, had south-west winds of force 9 and a high cross sea. The *Belfast* of Liverpool, in Lat. 8° 38′ N. and Long. 85°46′ E., experienced fresh south-west winds of force 8, and the *Sea Nymph*, in Lat. 7°13′ N. and Long. 85° E, had strong winds, overcast skies and a hazy atmosphere, but no rain. The *Iolanthe* at the head of the Bay, in Lat. 21° N., had calms and light winds, the *Clan Mackintosh*, in Lat. 18° 22′ N. and Long. 86° E., light airs, hazy weather and overcast skies, and the Floating Light-vessel *Comet*, at the entrance to the Hooghly, north-east airs of force 1 and cloudy weather. Hence strong winds prevailed over the whole of the Bay to the south of the disturbance. They fed the storm, but they did not form an integral part of the cyclonic circulation, and the direction of the centre could not have been accurately ascertained from them. Winds were strong for some distance to the north and west of the centre, but at distances of 150 miles and upwards they were exceedingly light, and in the neighbourhood of the Bengal and Orissa coasts were much feebler than the ordinary winds of May. The chief indication on the Bengal coast of bad weather to the southward was the very heavy swell which came up from the south-east.

The centre advanced in a north-north-east direction to the Arakan coast on the afternoon of the 17th.

Winds increased slightly in force on the 16th at Akyab. The weather began to be squally with rain, on the morning of the 17th and the sea to rise.

The barometer commenced falling at 10-30 A.M., and at mid-day the squalls became more frequent and violent. The wind increased to a gale at 4 P.M. and the weather was then very threatening, with frequent furious squalls. The squalls blew with terrific force, and heavy continuous rain fell after 7 P.M. and the sea continued to rise. The barometer fell to 28·98″ at 8-45 P.M. when the storm was at its worst and blowing with enormous force from the east-south-east. A short lull of five minutes occurred at 9 P.M., after which the wind suddenly shifted to south-south-west. The weather began to moderate very slowly afterwards, but the wind blew hard all night, with heavy and violent gusts.

May 18th.—The cyclone was now advancing directly to the Arakan Hills, which are of considerable elevation, averaging 3,500 feet and rising in their highest peaks to 7,000 feet. They proved to be too large an obstacle for the storm to surmount, and caused a rapid destruction of the cyclonic motion. Before 10 A.M. of the 18th the storm had completely broken up and disappeared. Light irregular winds and calms prevailed on the Arakan coast, and moderate south-west winds (decreasing in intensity as the day advanced) with cloudy and hazy weather over the Bay generally. The *Belfast* of Liverpool, in Lat. 12° 6′ N. and Long. 85° 13′ E., had fresh monsoon winds throughout the day. The log of the *Sea Nymph* (in Lat. 10° N. and Long. 84° E., at noon) records that the south-west winds in the part of the Bay she traversed decreased from force 7 to 4 during the course of the day. The *Kalima,* in Lat. 18° 30′ N. and Long. 85° 19′ E., had light south-west winds and fine clear weather, and the *Japan,* in Lat. 19° 41′ N. and Long. 89° 6′ E., had moderate south-south-west breezes (force 3) and fine clear weather.

Storm wave.—The calm area passed over Akyab, but was apparently of small extent. A storm wave broke over the Arakan coast and inflicted much loss upon the crops and grain stored up. About 100 people are reported to have been drowned or killed by falling houses during the storm.

Summary of facts.—The storm formed on the 14th and 15th to the west of the Andamans, and in front of the first local advance of monsoon winds up the Bay. It moved northwards on the 15th and 16th and on the 17th recurved through N.-N.-E. to N.-E., and finally crossed the Arakan coast at Akyab about 9 P.M. on the 17th. It broke up shortly afterwards without crossing the Arakan hills. The storm area was oval-shaped, the longest diameter on the 16th and 17th approximately coinciding with the direction of motion of the storm.

There are no data for the determination of the magnitude of calm area at the storm centre in this storm, beyond the fact that there was a lull of five minutes at Akyab when the centre was passing over the station. As the storm was then moving at the rate of 15 miles at least, this would prove that the breadth of the central area was at least $1\frac{1}{4}$ miles.

The path of the storm is approximately given by the following data :—

Day.	Hour.	Position. Lat. N.	Position. Long. E.	Distances passed over in previous interval.	Rate of advance in miles per hour during previous interval.
14th	Noon	11° 0′	89° 30′	} 150	6
15th	Noon	13° 0′	90° 0′		
16th	Noon	15° 40′	90° 45′	190	8
17th	2 A.M.	17° 30′	91° 10′	130	9
,, ...	Noon	18° 55′	91° 45′	105	10½
,, ...	9 P.M.	20° 30′	93° 0′	135	15

The following table gives the lowest barometric reading actually recorded on each day during the progress of the storm :—

Date and hour.	Observation. Actual.	Observation. Probable corrected.	Observation where recorded.
	"	"	
16th, midnight .	28·86	29·14	On board the *Pemba*, about 20 miles from the calm centre.
17th, 2 A.M. . .	28·83	29·09	Ditto ditto.
,, 8-45 P.M. . .	29·10	28·98	Akyab observatory, when the calm centre was passing over it.

The following table gives the data showing distances at which winds of force 8 or upwards were observed :—

Date.	Ship.	Bearing and distance of centre at noon.	Force.	Wind direction.
May 14th .	*Udstau* . .	200 miles E. by N. . . .	9	N.-W.
,, 15th .	*Udston* . .	210 ,, North-East . .	11	W.-N.-W. to S.-W.
,, ,, .	*Pemba* . .	329 ,, West-South-West .	8	S.-E. by E.
,, 16th .	*Udston* . .	352 ,, North-East .	10 to 12	W.-N.-W. to S.-W.
,, ,, .	*Pemba* . .	105 ,, South-South-West .	12	E.-N.-E.

A series of wind observations of unusual accuracy were carefully taken on board the *Rajputana* from which the following results, giving the bearing of the

centre with respect to the wind direction at intervals of two hours, have been worked out:—

Ship.	Time.	Wind direction.	Distance and bearing of centre.	Bearing angle.
Rajputana.	17th 2 A.M.	N.	110 miles E.-S.-E.	112°
	" 4 "	N.-N.-W.	114 " E.	112°
	" 6 "	N.-W.	125 " E. by N.	124°
	" 8 "	W.-N.-W.	125 " E.-N.-E.	135°
	" 10 "	W.-N.-W.	140 " N.-E.	112°
	" Noon	N.-W. by W.	170 " N.-N.-E.	86°
	" 2 P.M.	W.	190 " N.-N.-E.	112°
	" 4 "	W.-S.-W.	210 " N.	112°

The average of all the values of the bearing angle in the case of the *Rajputana* is 113°, or ten points almost exactly.

The mean of the values of the bearing angle as determined by the wind directions at Akyab from 4 P.M. to 8 P.M., is 116°.

History of the Storm of 26th June to 4th July, 1883.

This is an example of the class of storms which are generated during the rains (that is between June 15th and September 15th). The great majority of these storms form in the immediate neighbourhood of the land, and hence ships coming up the Bay mainly experience the weight of the westerly and southerly winds which feed into them. They give strong westerly gales near the head of the Bay to vessels bound for the Hooghly and the storms are sometimes described as westerly gales. They are true cyclonic storms, and as such to be avoided, if possible, by the mariner.

Weather previous to the formation of the storm.—The south-west monsoon of 1883 set in over the Bengal coast districts in the first week of June but was feeble. It gave moderate rain for a few days. A small storm began to form on the 12th between False Point and Saugor Island. It passed across the Balasore coast on the 14th and drifted through Chota Nagpur into Bihar, to a portion of which it gave excessive rain. The following gives the total rainfall from the 15th to the 17th at several places over which it passed :—

Gya	10·26 inches.
Bihar	22·17 "
Patna	12·71 "
Muzaffarpur	15·42 "
Hajipur	14·76 "

This disturbance broke upon the 18th and 19th, and was followed by a partial cessation of the rains in Bengal. The air became drier, skies were less clouded, and the winds fell off in strength. In the Bay south-west monsoon winds prevailed everywhere, but they were nowhere of force greater than 3 or

4, except during occasional rain squalls, such as occur at intervals during the prevalence of the south-west monsoon in the Bay.

The observations of the 25th June showed that a marked change in the weather was commencing. The barometer in South Bengal was two-tenths of an inch above its normal height. Winds were very unsteady and variable in Bengal and over the north of the Bay. Heavy rain squalls and dark overcast skies prevailed over the south-east of the Bay between Lat. 14° and 19° N., and close sultry weather with calms or light airs, clear skies and a smooth sea to the north of Lat. 20° N.

Over the greater part of the Bay south-west winds were blowing, but they were unusually light, and weather was fine in the north and centre. Thus, the *Bancoora*, passing round Ceylon and entering the Bay, had light to moderate breezes and fine weather. The steam-ships *India*, *Himalaya* and *Roma*, all in the centre of the Bay in about Lat. 16° N., had moderate breezes and cloudy skies with occasional rain squalls. The *Comilla*, in Lat. 20° 13′ N. and Long. 92° 28′ E., at noon, had fine clear weather and a smooth sea and the *Prince Amadeo*, in Lat. 19° 23′ N. and Long 85° 56′ E., gentle winds, close sultry weather and a smooth sea. These facts sufficiently establish the character of the weather in the Bay on the 25th. There was no indication of stormy weather at this time in any part of the Bay. Moderately strong south-west winds, of force 3 to 5 or 6, were blowing over the south-east of the Bay near the Andamans and Nicobars. The winds in the south and centre of the Bay increased in force during the day and weather became squally and unsettled near the head of the Bay on the 26th. Thus, the *India*, in Lat. 19° 36′ N. and Long. 86° 33′ E., at noon, had strong winds and squally weather on the morning of the 26th. The *Amadeo*, about 40 miles to the north-east of that vessel at noon, had heavy cloudy unsettled looking weather, with much lightning during the day. The *Comilla*, in Lat. 22° 21′ N. and Long. 91° 50′ E., had squally weather with very heavy continuous rain during the afternoon and evening. These were the first indications of the impending storm. The weather became more unsettled and threatening in appearance during the day, heavy rain began to fall in the north of the Bay, the barometer fell rapidly, and winds began to draw into the area of falling barometer from the north as well as the south.

Heavy rain also commenced in the neighbourhood of the Arakan Coast and increased the force of the south-west winds in the north of the Bay, and the disturbance thus initiated was shortly afterwards followed by the formation of a whirl near the head of the Bay. The winds on the Bengal Coast, although still feeble, settled down to north-east, the usual indication during the rains of the formation of a cyclonic whirl at the head of the Bay.

History of the Storm.—*June 27th.*—This whirl gained rapidly in force during the night of the 26th, and on the morning of the 27th it had developed into a small but dangerous storm. The chief features of the storm at this time

were the violent winds in the south-east and east quadrants. The centre of the cyclonic circulation at noon of the 27th was in Lat. 20½° N. and Long. 89¾° E. or about 100 miles to the south-south-east of Saugor Island. The British Indian steam-ship *Pemba*, which was in Lat. 16° 13′ N. and Long. 93° 30′ E., at noon, and was advancing northwards along the Burma Coast, had "a strong gale, with furious squalls, which blew away the sails and awnings in the afternoon," and the *Comilla*, in Lat. 22° 21′ N. and Long. 91° 50′ E., at noon, had "hard squalls and wild squally weather" between 4 P.M. and midnight. In the western and northern quadrants skies were overcast with rain, and weather was unsettled with occasional squalls, but the winds were as yet feeble, varying in force from 1 to 4 or 5, except perhaps in the immediate neighbourhood of the centre.

A large number of vessels were off the mouth of the Hooghly, waiting to enter the river. Their logs agree in stating that the winds were unsteady and variable in direction, but increased considerably in force during the day, the weather became more unsettled and squally, skies were overcast, and heavy rain showers fell at frequent intervals. The centre of the disturbance was almost stationary on the 27th. If it was moving, its rate of motion was so small as not to produce any appreciable change of wind direction, as recorded on board the light vessels and pilot vessels near the entrance to the River Hooghly.

June 28th.—The storm continued to increase in intensity during the night of the 27th, and on the morning of the 28th the barometer had probably fallen to 29·00″ at the centre, as readings between 29·1″ and 29·2″ were recorded on board ships at distances of 20 to 40 miles from the centre during the day. The various observations taken on board ships indicate that the centre at 10 A.M. of the 28th was in Lat. 21° N. and Long. 88° 45′ E., and moving west by north at a rate of about 3 miles per hour.

The weather over the north of the Bay was now very wild and stormy. The following gives the weather reports in full of several vessels near the head of the Bay which encountered the weight of the storm in different quadrants.

The *Comilla* at noon was in Lat. 21° 4′ N. and Long. 89°31′ E. and proceeding from Chittagong to Calcutta, and hence in the eastern quadrant at some distance from the centre. At 4 A.M. she had a very high sea from south and south-west. Winds were very variable in force, with very hard squalls from south-south-west. At noon hard squalls came up from the south-south-west. At 6-30 P.M. there was very heavy rain, and a tremendous sea from south-south-west and south-west. At 7-30 P.M. a terrific sea carried away the starboard cutter. At 8 P.M. terrific squalls from south-west passed over the vessel, which split the new jib and staysails. At midnight the winds were from south-west and of force 11.

The *Saint Magnus* and *British Princess* were in the south-west quadrant during the greater part of the day, and about 40 miles from the centre, when they were nearest. The weather as described in the log of the *British Princess* was as follows :—

4 A.M.—Heavy rain, lightning and thunder, high confused sea.
8 A.M.—Heavy squalls, with torrents of rain.
Noon.—Fresh gale : high and confused sea.
8 P.M.—Heavy squalls, torrents of rain, high sea.
Midnight.—Force of wind 11. Furious squalls, torrents of rain and high sea.

The log of the *Saint Magnus* runs as follows :—

4 A.M.—North-west wind, force 6. Heavy gusts and heavy continued rain.
8 A.M.—Wind north-west, force 6. Strong winds and high sea.
Noon.—Wind north-west, force 4. Wind and sea more moderate.
4 P.M.—Wind west-south-west, force 6. Terrific squalls. Tremendous seas at times.
Midnight.—Wind south-west, force 10. Furious gale, high squalls and heavy sea.

The *Pemba*, about 200 miles to the south-east of the centre, had strong gales (force 9) with a heavy sea. The light-vessels at the entrance to the Hooghly, which were only about 30 miles to the north or north-west of the centre, had winds not exceeding 5 in force during the day, and it was not until late in the evening that they began to experience the strong winds of the east quadrant and felt the force of the storm. The contrast between the violent winds and furious squalls in the southern and eastern quadrants at considerable distances from the centre (up to 150 or 200 miles), and the moderate winds and squalls at distances of 30 or 40 miles in the northern and western quadrants, was one of the most conspicuous features of this storm, as it is probably of all the small cyclonic storms of the rains proper.

June 29th.—The observations of the 29th show that the barometer had fallen rapidly in South-West Bengal and Orissa, and was nearly half an inch below its normal height in June. Winds were from two to four times their ordinary strength in June, and very heavy continuous rain had fallen during the preceding 24 hours over the whole of Orissa and South-West Bengal. These observations and the logs of vessels show that the storm continued to increase in extent during the night of the 28th, and covered a larger area than it had hitherto done. It intensified slightly, but there is no evidence that the barometer fell below 29·0″ at any time during the storm. The lowest recorded readings were 29·14″ at the Upper Gasper light-ship at 10 A.M., and 29·108″ at 4 P.M. of the 29th. The storm centre continued to drift slowly to the westward during the night of the 28th, and was in Lat. 21°30′ N. and Long. 87°55′ E. at 10 A.M. of the 29th, or about 35 miles to the west-by-north of its position at 4 P.M. on the previous day, and was advancing at a rate not exceeding 3 miles per hour. It had passed between the Intermediate and Upper Gasper

light-vessels, and was about 5 miles to the west. The vessels in the north of the Bay continued to experience violent cyclonic winds and a dangerous sea. The *Pemba*, 200 miles to the east of the centre in the morning, had a fierce gale, with a high irregular sea and hard squalls blowing with hurricane force. The log of the *Comilla*, which was about 60 miles to the east of the centre, describes the weather in the eastern quadrant as a "terrific storm, continued rain, squalls of hurricane force, with a mountainous and dangerous sea running." The *Saint Magnus* was about 45 miles to the east of the storm centre, and experienced a heavy gale with terrific gusts and a high sea; the *Prince Amadeo*, 75 miles to the east, a strong gale with furious squalls and a very high sea. All the ships' logs agree in assigning a force of 10 and 11 to the winds in the southern and eastern quadrants. At Saugor Light-house, which was only 20 miles to the north of the centre at 10 A.M., moderate winds were felt, and at the Upper Gasper light-vessel, not more than 5 to 10 miles to the north of the centre, the winds were of force 5 to 6.

The captain of the *Comet* floating light-vessel thus describes the weather on the 29th—" Weather was very threatening in the morning, and a heavy sea came up from the south-east. The wind was very variable, shifting all round the compass. Rain-squalls passed up frequently. At midnight it was blowing a furious gale." The captain of the *Meteor* floating light-vessel describes it as follows:—" The sea was very rough, and a squall from south-west came up at 8 A.M. of the 29th. Frequent heavy rain-squalls passed over the vessel. The wind shifted to south-west at 10-30 A.M. The barometer began to rise at 2 P.M. During the evening a strong south-west gale blew, and frequent terrific rain-squalls passed over the vessel."

The centre was in Lat. 21°35′ N. and Long. 87°30′ E. at 4 P.M. of the 29th, and its velocity was now increasing. Its rate did not, however, yet exceed 5 miles per hour.

June 30th.—The storm centre crossed the Orissa Coast between False Point and Balasore during the night of the 29th, and was advancing through Orissa on the morning of the 30th. Its position at 10 A.M. of the 30th was in about Lat. 22° 0′ N. and Long. 84° 0′ E. It was hence travelling much more rapidly than hitherto. The barometric depression at the centre was not so great, and the air motion was not so regular as at sea. This was evidently due to the resistance and action of the Orissa hills. The weather rapidly improved at the head of the Bay. The *Pemba* had a moderate breeze and clear weather at noon of the 30th; the *Saint Magnus*, a strong breeze with hazy weather at noon and moderate and fine weather at 8 P.M., and the *Comilla*, overcast hazy weather at noon, and fine weather at 4 P.M. All these vessels were to the north of Lat. 20° N.

The above account illustrates fully the chief features of the more dangerous storms of the rains proper in the Bay of Bengal. They commence to form after a partial cessation of the rains in Bengal. Heavy rain begins to fall, generally near the Arakan Coast or at the head of the Bay. This causes a greater inrush of moist winds from the south, which not only prolongs and intensifies the rainfall, but generally sets up a whirl near the head of the Bay, which, if conditions are favourable to its growth, increases and intensifies and becomes in the course of a day or two a dangerous storm. The most prominent feature of these storms is the very violent winds and furious squalls in the south-east quadrant, which extend to very considerable distances from the centre. The storm moves very slowly in the earlier stages, and hence the stormy weather or westerly gales attending them may continue for several days; but when the cyclone is fully developed it generally moves or shoots off rapidly to the Orissa Coast (or the Bengal Coast, but much more rarely), and very shortly after it passes landwards the weather begins to improve at the head of the Bay, and the winds decrease in force, and in a short time normal or ordinary south-west monsoon winds (force 3 to 5) are again established at the head of the Bay.

July 1st.—The history of the storm after it reached the Orissa Coast is given more briefly. The centre travelled at a mean rate of about 15 miles per hour on the 30th, and was in about Lat. 22° N. and Long. 81° E. at 10 A.M. of the 1st. The storm gave excessive rain to Orissa, and very heavy rain fell in the districts of the Central Provinces through which it passed on the 1st, which flooded the rivers and carried away bridges on the railways and roads and interrupted traffic.

July 2nd.—The storm passed out of the Central Provinces into Central India on the morning of the 2nd. The centre was near Indore at 10 A.M. in Lat. $22\frac{1}{2}$° N. and Long. 76° E., so that it had advanced at a mean rate of about 14 miles per hour during the previous 24 hours.

July 3rd.—The storm crossed through Gujarat into Cutch, and was between Bhuj and Rajkot in Lat. $23\frac{1}{2}$° N. and Long. $69\frac{3}{4}$° E. at 10 A.M. of the 3rd. It had continued to give excessively heavy rain to the districts through which it marched. At Rajkot 9·85 inches were recorded on the 3rd. The storm had thus advanced unbroken across the head of the Peninsula from the Orissa Coast to Cutch, a distance of 1,400 miles, in about 80 hours. It was now in the immediate neighbourhood of the Arabian Sea, into which it passed during the afternoon of the 3rd.

July 4th.—It continued to exist as a dangerous storm for at least 36 hours longer as it passed over the British Indian Steamer *Oriental* on the evening of the 4th in Lat. 24° 14′ N. and Long. 63° 30′ E., or at a distance of aoout 400

miles from the Cutch Coast. The following is the account of the storm given by the captain of the *Oriental:*—

"I experienced a very heavy cyclone on the night of the 4th July in Lat. 24° 14′ N. and Long. 63° 30′ E. at 8 P.M. I had a light westerly breeze, with the usual south-west swell on the morning and afternoon of the 4th and the barometer was steady until 9 P.M., at which hour the wind began to increase slightly, hauling northerly. As I noticed the glass was falling rapidly, I gave the order to take in all sail. While clewing up the fore-topsail, the whole force of the cyclone struck her, carrying away fore-topsail, foresail and awnings fore and aft. I at once eased down to keep her before the wind till the saloon; sky-lights could be secured, as I was afraid to bring her to the wind till they had been secured. At 11·30 P.M. a sea carried away both quarter boats on the starboard side. At midnight I brought the ship to the wind and sea. The reading of the barometer at that time was 28·56″. Violent winds continued until 4 A.M., when the wind commenced to moderate. The sea continued very heavy, and I was not able to stand on my course until noon."

It would appear from this account that the storm not only intensified again after leaving the coast, but that it moved more slowly than while crossing the land. In both respects it agrees with what has been observed in other storms that have passed into the Arabian Sea from the Bay of Bengal.

It will thus be seen that this class of storms is remarkable chiefly for the contrast between the strong winds which are experienced at very considerable distances to the east and south of the centre, and the light winds at distances not exceeding 30 to 50 miles to the north and west of the centre.

Summary of facts.—This storm began to form on the 25th at the head of the Bay after a short break in the rains which followed the first large advance of monsoon winds up the Bay into Bengal. It remained almost stationary on the 26th and 27th, and began to move very slowly to the westward on the 28th and crossed the Balasore Coast a few miles to the north of Balasore about midnight of the 29th. It marched in a westerly direction across the Orissa Hills into the Central Provinces, diminishing to some extent in intensity and moving somewhat irregularly. It, however, began to draw large supplies of vapour from the Bombay Coast, and again increased in strength, and continued its march across the head of the Peninsula at an average rate of about 15 miles per hour. It advanced through Cutch, and thence passed out into the Arabian Sea on the evening of the 3rd, and was some distance to the south of Kurrachee on the morning of the 4th. It passed over the steam-ship *Oriental* on the evening of the 4th in Lat. 24° 4′ N. and Long. 63° 30′ E. or 220 miles west by south of Kurrachee. Nothing is known of its history after that date, but it probably broke up shortly afterwards. The storm had hence an unbroken existence of at least ten days. It presented comparatively small differences of intensity at different periods, taking into consideration the very different conditions of its existence at sea, and afterwards whilst advancing across the hills, plateaux and river valleys of the head of the Peninsula.

The following table gives the position of the centre at the hours stated

from the 27th of June to the date of its disappearance in the Arabian Sea beyond the limits of India, and its rate of motion throughout:—

Date.	Hour.	Position of Centre.		Distance travelled during preceding interval.	Rate of motion in miles per hour.
		Latitude N.	Longitude E.	miles.	
June 27th . . .	Noon .	20° 30′	89° 45′	...	...
	4 P.M. .	20° 35′	89° 35′	12	3
„ 28th . . .	10 A.M. .	21° 0′	88° 45′	62	3½
	Noon .	21° 3′	88° 40′	6½	3¼
	4 P.M. .	21° 10′	88° 30′	13	3¼
„ 29th . . .	10 A.M. .	21° 30′	87° 55′	45	2½
	Noon .	21° 30′	87° 50′	5½	2¾
	4 P.M. .	21° 35′	87° 30′	22	5½
„ 30th . . .	10 A.M. .	22° 0′	84° 0′	230	13
	4 P.M. .	22° 0′	83° 30′	32	5⅓
July 1st . . .	10 A.M. .	22° 0′	81° 0′	162	9
	4 P.M. .	22° 0′	79° 45′	80	13⅓
„ 2nd . . .	10 A.M. .	22° 30′	76° 0′	245	13½
	4 P.M. .	23° 30′	74° 30′	120	20
„ 3rd . . .	10 A.M. .	23° 30′	69° 45′	308	17
	4 P.M. .	23° 45′	68° 45′	66	11
„ 4th . . .	8 P.M. .	24° 14′	63° 30′	300	12

The following table gives the lowest recorded reading of the barometer, the average barometric height at the place and the amount of the greatest known barometric depression at 10 A.M. on each day:—

Date.	Place.	Lowest 10 A.M. barometric reading.	Average 10 A.M. barometric height at place on date.	Greatest barometric depression.
June 29th . . .	Bay (Sandheads) . .	29·140″	29·602″	·462″
„ 30th . . .	Sambalpur . . .	29·353	29·589	·236
July 1st . . .	Seoni	29·463	29·624	·161
„ 2nd . . .	Indore	29·410	29·662	·252
„ 3rd . . .	Bhuj	29·326	29·616	·290
„ 4th . . .	Kurrachee . . .	29·380	29·589	·209

One of the most remarkable features of the storm was the strength of the westerly and southerly winds in the south and south-east quadrants, more especially when contrasted with the weakness of the northerly winds at distances of only 20 and 30 miles from the centre. The strong westerly and southerly winds extended south as far as Lat. 18° N., or to at least 300 miles from the centre.

THE PORT BLAIR CYCLONE OF NOVEMBER 1ST TO 7TH, 1891.

This storm is of great interest, more especially on account of the following features :—

(1) It originated in the Gulf of Siam outside the Indian area. It advanced across the Malayan Peninsula into the Andaman Sea and Bay of Bengal. It is the first cyclone in the Bay on record of which there is clear and decisive evidence that it originated outside the Bay.

(2) The storm was in its earlier stages of small extent although of great intensity. The storm winds were hence of extraordinary violence, in this respect resembling the False Point Cyclone. The storm increased in extent without altering in intensity as it approached the head of the Bay. It had an existence of at least nine or ten days and was during upwards of seven days an intense cyclone.

(3) The path of the storm in the Bay was almost unique on account of its great recurvature. Its course was west-north-west in the Andaman Sea. It recurved rapidly through north-west and north to north-east and east-north-east in the centre and north of the Bay. In consequence of the recurvature of the storm, several ships encountered it twice in their passage up the Bay. The storm was almost unique in this respect.

Weather in India and the Bay of Bengal preceding the storm.— The south-west monsoon of 1891 was noteworthy in several respects. It gave about the normal amount of rain, on the whole, to India, but it was much more irregularly distributed than usual. The rains were excessive in the North Western Provinces, Central India, Berar, the Central Provinces, Arakan and Lower Burma, and were, on the other hand, very scanty and deficient in Rajputana, Mysore and South and Central Madras. The rains commenced about a month later than usual and ceased in the first week of October over the whole of Northern and Central India. The south-west monsoon withdrew suddenly to the south of the Bay at the beginning of the second week of October and gave very heavy rain to the whole of Central and South Madras (to the south of Nellore) and Mysore during the remainder of the month. The rainfall of the month was very deficient in Bengal, Assam, Bihar, North Madras, and the Deccan. A noteworthy feature of the month was the entire absence of cyclonic storms in the Bay.

At the commencement of October, light variable winds prevailed in the north and centre of the Bay and were decreasing in force. On the 5th

light airs and calms were reported by all vessels in that area. Light north-east winds set in at the head of the Bay on the 8th and extended rapidly southwards over the north and centre of the Bay. They also increased in force so that on the 16th north-east winds of force 1 to 4 obtained over the north-west and centre of the Bay. During the whole of this period, south-west and west-south-west winds with squally weather and more or less heavy rain prevailed in the south of the Bay. No important change in the winds or weather occurred during the remainder of the month. Fine clear weather with light to variable north-east winds predominated in the north of the Bay and cloudy squally weather with much rain in the south, south-east, and south-west of the Bay. As the storm under discussion formed in the Gulf of Siam, the weather in the Bay throws no light on its origin. Its track was to some extent determined by the pressure conditions at the end of the month. The following is a brief statement of these conditions :—

(1) The mean pressure of the month of the whole Indian area was considerably in excess, by amounts averaging ·036″.

(2) The excess was greatest in Berar, the Central Provinces and the North Deccan, and hence there was a moderately large local excess of pressure in that area.

(3) The excess was least in amount in Burma, the Andamans and Southern India, and hence there was a moderate local deficiency of pressure which was greatest in Malabar and across the south and south-east of the Bay.

In consequence of these peculiar features the mean distribution of pressure in October 1891 differed in some important respects from the normal distribution, *e.g.*,—

1st.—The range of pressure over India was considerably greater than usual.

2nd.—Pressure was less uniform in the Bay than usual and was high in the north-west of the Bay, so that there were slight gradients favouring the prevalence of steady northerly winds.

3rd.—Pressure was somewhat lower in the east than in the west of the Bay, thus giving pressure relations between the Burma and Madras coasts opposite to those which usually obtain in October.

Origin of the storm.—The circumstances attending the origin of the cyclone have not been determined in the absence of information. The storm is known to have crossed the Gulf of Siam on the 30th and 31st of October. Dr. Doberck, Director of the Honkong observatory, states that no bad weather was reported in the China Seas from the 23rd of September to the 12th of November. He also adds that he has come across only one case of a small cyclone which originated in the Gulf of Siam and advanced westwards, probably across the Malayan Peninsula.

It is hence, on the whole, probable that the storm originated in the Gulf of Siam on the 28th and 29th of October and that it had developed into a small cyclonic storm of considerable intensity on the morning of the 30th, when as shown by the available information it was moving westwards across the Gulf of Siam.

History of the storm.—According to the few reports of the storm received from Siam the cyclone was fully developed on the 30th, and advanced over the Gulf of Siam along a westerly course on the 30th and 31st. The storm passed over the island of Koh Samuie on the evening of the 31st, when the S. S. *Rainbow* capsized near that island and the officers and crew of 30 men and 3 passengers with the exception of 6 natives were all lost.

The storm crossed the Malayan Peninsula during the night of the 31st and almost completely wrecked the towns of Bandon and Chaiya, the latter being one of the largest towns on the Gulf of Siam. The storm broke out at Chaiya at 11 P.M. of the 31st and lasted until 3 A.M. of the 1st November. A storm wave flooded the town to the depth of 7 or 8 feet. Three hundred and eighty-seven religious buildings and 4,238 other buildings were more or less completely destroyed, and 109 people died by drowning or by falling houses, etc. At Renong, on the west side of the Peninsula, the storm lasted from about 1 A.M. to 7 A.M. of the 1st. The destructive part of the storm area averaged about sixty miles in breadth. The severity of the storm in this belt was very great as houses and trees, etc., were all levelled to the ground and the roads rendered impassable by the rains and fallen trees.

The storm at this stage advanced at an average rate of about 18 miles per hour, and passed out into the Andaman Sea early on the morning of the 1st November. It was of comparatively small extent, the inner area of hurricane winds not exceeding 80 miles in its longest diameter and 60 miles in its shortest diameter at right angles to the direction of motion.

It advanced over St. Matthew's Island in Lat. 10° N. and Long. 98¼° E. on the morning of the 1st. Large trees were uprooted by the storm and the foliage either stripped from the trees or blackened as if scorched by fire.

The following is a brief history of the progress of the storm in the Andaman Sea and Bay of Bengal.

November 1st.—Pressure was very considerably above the normal on the 31st of October, but was beginning to give way over nearly the whole of India. The changes were, however, small and the pressure distribution in the Indian land area on the morning of the 1st November was similar to that of the 31st October. The chief features were:—

(1) Pressure was in excess over the whole of India by amounts averaging very nearly a tenth of an inch.

(2) Pressure was most largely in excess in the area stretching from the South Deccan and Circars to Bihar and the North-Western Provinces. That area was hence one of local excess of pressure.

(3) The excess of pressure was least in amount in Lower Burma and the south of the Bay and off the Malabar coast. The cyclone was entering this area of local deficiency of pressure in the Andaman Sea, and was hence intensifying the deficiency.

Pressure was very uniform over North-Western and Central India. Steepish gradients obtained in the Peninsula and the north of the Bay. In the Bay (excluding the Andaman Sea) winds were slightly stronger in the northern half of the Bay than in the southern half. They ranged in force from 4 in the north of the Bay to 2 and 3 in the centre and south of the Bay.

Winds on the 1st were hence strongest in that part of the Bay where they are usually weakest in November, and *vice versâ*.

Assuming that the storm centre passed over Chaiya between 1-30 A.M. and 2 A.M., and that it was travelling on a straight course with an average velocity of 18½ miles per hour, its position at 8 A.M. of the 1st would be in Lat. 9° 50′ N. and Long. 97° 30′ E. This agrees satisfactorily with the land and marine 8 A.M. meteorological data of the day.

The data show that winds were feebler and more variable at the entrance to the Bay than is usual in November. The S. *Eurydice* in Lat. 4° 45′ N. and Long. 92° 40′ E. had moderate south-west winds and occasional squalls. Five vessels in addition to the S. *Eurydice* were between Lat. 4° N. and 8° N. All had light airs and calms in the morning with a smooth sea.

Fine clear weather obtained over the remainder of the Bay. Winds were somewhat stronger than their mean force in November, and ranged from 2 and 3 at the head of the Bay to 4 and 5 on the Coromandel and Madras coasts.

The 8 A.M. observations at the Burma coast stations gave no indication of the existence of the cyclone in the Andaman Sea. The barometer had fallen slightly, but was still above the normal of the day. Winds were light, and blowing from some northerly point at all stations, and were generally below their normal strength.

Several vessels which were near the Lower Pegu coast during the day had fine clear weather throughout.

The weather over the greater part of the Andaman Sea at 8 A.M. of the 1st was fine with light to moderate winds. The S. *Marpesia* passed into the storm area in the afternoon. She had light winds at noon. Winds began to increase very rapidly at 3 P.M. and blew with hurricane force from 9 P.M. to 3 A.M. of the 2nd. The wind carried away the jib-boom and fore-top-mast head at 3 P.M. and the fore and main topsails and fore topmast staysail at 9 P.M. She had continuous rain during the evening and night. The corrected reading of her barometer at midnight was 28·85″ at which hour the centre was probably not more than 10 or 15 miles to the east-north-east.

November 2nd.—The decrease of pressure which had commenced on the

31st continued on the 1st. The changes were small and less than ·05″, except in the greater part of the Bay and the adjacent coasts (except Tenasserim).

Skies were clear and weather fine over the whole of India except in Lower Burma and Southern India, where they were heavily clouded. The peninsula south of Lat. 15° N. had received general light to moderate rain during the previous 24 hours.

The cyclone passed over Port Blair between 2 and 3 A.M. of the 2nd and then crossed out from the Andaman Sea into the Bay of Bengal. Assuming that its direction and rate were the same on the morning of the 2nd as on the 1st, a supposition which is confirmed by the marine data, the centre at 8 A.M. would be in Lat. 12° 10′ N. and Long. 91° 10′ E.

The data show that no change had as yet occurred in the north of the Bay. Fine clear weather, with moderate north-east winds, obtained over the whole area to the north of Lat. 18° N. Winds were of average force 4·1 as compared with 3·5, the normal force in November. The northward extension of squally weather was shown by the fact that the vessels between Lat. 8° N. and 20° N. and to the east of Long. 88° E. had cloudy weather with occasional showers and squalls in the afternoon and evening.

Weather in the south of the Bay had changed considerably during the previous 24 hours and was now squally with much rain and with moderate south-west to west winds. The mean force of the winds experienced by seven vessels to the south of Lat. 8° N. in the morning was 3·7, whereas on the morning of the 1st the average force was only 2·0. The data hence show clearly that moderate south-west winds now prevailed in the south of the Bay, where on the 1st and preceding days calms and light and variable airs had obtained. The weather was also more or less squally, and the squalls increased in severity during the day. The data are not sufficient to show clearly how far these squally winds extended up the south-east of the Bay, as there is no information available for the area between Lat. 8° N. and 11° N. It is, however, very probable from the rapid changes in the winds and weather that this extension was due to the action of the storm, and that the humid south-west winds of the south of the Bay now extended northwards as far as Lat. 12° N. in the south-east of the Bay, and were feeding into the storm.

The cyclone passed over Port Blair early on the morning of the 2nd. The observer, Mr. Carroll of the Medical Department, who was then the meteorological observer at the Port Blair Observatory, took a valuable series of observations during the storm and also supplied information from various sources.

The following is Mr. Carroll's account of the storm :—

"On the afternoon of the 1st instant, at about 2 P.M., rain clouds, banking up from the east and north-east, soon overspread the sky and burst, attended by strong wind. After a good shower, registering 0·60 inch of rain, the wind abated, leaving the usual gloomy state of weather experienced on a monsoon day. During this shower I noticed that there was some

disturbance in the upper currents of air; for, the lower clouds—though moving chiefly from east-north-east, were very frequently unsettled, seeming to falter, circle and then move on—the wind-vane at that time was oscillating between north and east-north-east. However at 4 P.M. the wind having fallen, to all ordinary appearance mischief was not expected. About 1 A.M. on the 2nd instant the wind rose in fierce gusts from the north. This was the first indication of coming trouble. My barometer registered 29·602″ at 1 A.M. The mercury continued to fall; at 2 A.M. it registered 29·404″; the wind-vane circling at very great speed, and the wind so strong apparently from north-east, that I could not force my way up the ladder to the anemometer. At this time the shingles from the convict barracks and hospitals were being ripped up by the wind. The I.M.S. *Enterprise*, then in harbour, was either being driven or was forcing her way out at the southern entrance of the Ross harbour, and was whistling, apparently in distress (for, as it so happened, it was their death signal). She was driven on the rocks when about half-way out, and was a total wreck, losing all but six hands, before daybreak. Between 2 and 3 A.M. there was a sudden lull, then the wind veered round to southward, and by 3 A.M. the cyclone was at its worst. The barometer reading was 28·502″; and, after a very hard struggle to reach the anemometer a reading was registered as 499·9. Two steam barges, several large lighters and many boats in the harbours had lost their anchorage, and were at the mercy of the wind and waves. They have all been more or less smashed or otherwise destroyed. Trees of great size were ripped up by the roots. Cocoanut trees were broken off at the crowns like mushrooms; areca-nut trees snapped like match-wood and the roofs and sides of nearly every building destroyed. At 4 A.M the barometer rose to 28·680″. Another attempt was then made to reach the anemometer. This was accomplished with very great difficulty, and the reading taken at 105+1·4 miles, so that in the hour the wind travelled (505—499·9)+106·4=111·5 miles. The wind-vane had been wrenched off. About 15 minutes after leaving the anemometer the cups were wrenched off too; the platform and hand-rail leading to the instruments were broken off.

The more important inferences from the account are:—

1st.—The storm consisted of an inner area of destructive hurricane winds and of an outer area of comparatively moderate winds.

2nd.—The inner storm area of hurricane winds was not more than 45 miles in width on the east side of the island, and 38 miles on the west side.

3rd.—The diameter of the storm area in which the winds were strong enough to break the branches of trees was 54 miles.

4th.—The strongest winds, according to Mr. Carroll, lasted from 1 A.M. to 5 A.M., giving a duration of four hours for the passage of the inner storm area across Port Blair, corresponding to a diameter of 75 miles (assuming the velocity of the storm at this stage to have been $18\frac{3}{4}$ miles).

5th.—The inner storm area was, hence, almost certainly elliptical-shaped, the longest diameter (lying east and west) probably not exceeding 75 or 80 miles, and its shortest diameter (lying north and south) not exceeding 50 miles. A comparison of these data with those of the dimensions of the inner storm area or typhoon when crossing the Malayan Peninsula shows that the storm was

practically unchanged in shape or dimensions, and that the direction of the longer diameter of the storm area in both cases approximately coincided with the direction of advance of the storm.

The following account of the destruction caused by the storm at Port Blair was given by Mr. Carroll:—

"From the Chief Commissioner down, every man, woman and child in the settlement more or less suffered from wet and exposure, having either partly or wholly unroofed houses as shelter. All the convict barracks and hospitals in the settlement, bazars, and self-supporters' villages are in most instances complete wrecks, and at present no dry spot is available. The sea-face walls and stone jetties have been destroyed, stones weighing several pounds upheaved and scattered for many yards over roads and adjoining spaces. Roofs of the Co-operative stores, Asiatic Steam Navigation Company's Agent's office, Port Officer's office, Volunteer Drill Hall, the extensive Commissariat godowns and Marine workshop sheds lie scattered over the roads, every tree on Ross Island has been either uprooted or had its branches broken off, and the large trees of the forests deprived of their foliage stand out as so many bare poles. Sea gulls were found dead on the roads, and birds on the wing were dashed against the buildings. The destruction of buildings has been attended with wounds, injuries and loss of life. At this present moment I do not know the exact numbers, but I am sure I am within bounds in saying that about 40 lives have been lost and thrice that number injured by the falling and collapsing of buildings. All but six of the whole crew of the *Enterprise* (79 in number) have been lost and several lightermen drowned."

The only vessel which was within the storm area during the day was the ship *Bann*. She had light unsteady north-east breezes up to 10 A.M., when she began to feel the influence of the cyclone. At noon she had a strong to heavy gale from the west with furious squalls and heavy rain. The storm centre was at that time in about Lat. 12° 10′ N. and Long. 91° 15′ E., and advancing in a west-north-west direction. The *Bann* was less than 80 miles to the west of the centre at that hour. The fact that she had light variable breezes until 10 A.M., when she was probably not more than 100 miles from the centre, confirms the previous conclusions as to the small magnitude of the storm.

November 3rd.—The barometric changes of the previous 24 hours were small in amount at all the Indian land stations, and under ordinary circumstances would have been considered of little or no significance.

Skies were thickly clouded in Burma, and were clouding over in Bengal.

The rapid extension of cloud over the Bay area and in Bengal and the Peninsula is one of the most characteristic features of storms in the Bay of Bengal.

The observations show that weather was reverting to its normal character in the Andaman Sea. The S.S. *Goa*, which left Moulmein for Rangoon at noon, had fine weather with light winds, and the S.S. *Kola*, which left Rangoon for Akyab, had light winds and fine clear weather during the day and night of the 3rd in the north of the Andaman Sea. The S.S. *Shahjehan* between Rangoon and Port Blair had cloudy weather, moderate breezes and a slight sea throughout the day. South-east to east winds prevailed over nearly the whole area.

The observations show that weather was not much changed in the south of the Bay. Skies were more clouded and winds slightly stronger. The storm was in the centre of the Bay, and its influence was extending rapidly northwards. Weather was squally, with strong easterly winds, over the whole of the north of the Bay in the morning, and the winds intensified rapidly during the day, so that the F. L. V. *Canopus* at the Intermediate Station had a fierce gale from east (force 9) in the evening. The S.S. *Meanatchy* and *Arratoon Apcar* and the F. L. V. *Canopus* had a strong southerly swell during the day, due to the storm in the Bay, indicative of its existence and approximate position.

The information when charted shows that the most probable position of the centre at 8 A.M. was Lat. 14° 10′ N. and Long. 87° 20′ E.

The only vessels in the storm area on this day were the *Bann*, *Lena* and *Arratoon Apcar.*

The ship *Lena* passed through the eastern quadrant of the storm in the day and continued on her course up the Bay towards the Hooghly, and was again involved in the cyclone on the 6th, near the Sandheads. She encountered a strong to fierce gale, with terrific squalls. Her observations establish that she was within the inner storm area, and probably not more than 40 miles from the centre between 8 A.M. and noon, during which period she appears to have been carried some distance round the eastern quadrant.

The *Arratoon Apcar* was upwards of 340 miles to the north-east of the centre at 8 A.M., at which time she had strong easterly breezes, with occasional very hard squalls. The weather became worse during the evening, and from 8 P.M. to midnight, when she was about 350 miles to the east-north-east of the centre, she had a hard gale with squalls of "hurricane and terrible force," and very heavy rain.

It is also noted that she had a fresh north-east gale with heavy squalls and a dangerous cross sea at noon, and that the wind at 1-30 P.M. fell away to a calm, which lasted for three minutes, after which the wind came down for some time from west. This appears to point to this vessel having passed through a small subsidiary whirl or depression. The barometer observations, it may be noted, are also in accordance with this supposition.

The S. *Bann* was from 250 to 300 miles to the east of the centre on the afternoon and evening of the 3rd. She had a strong to a fresh gale during the whole of the afternoon. The weather improved during the night. She had strong south-east winds, with occasional squalls and rain, during the next 36 hours.

The whole of the observations indicate that the storm area was extending and that the extension was occurring most rapidly in the eastern and southern quadrants of the storm area. This is most clearly shown by the weather experienced by the S.S. *Lincolnshire, Regulus,* and *Arratoon Apcar.* The S.S. *Saint Regulus,* 350 miles north-east of the storm centre at noon, had hard

squalls with heavy rain; the S.S. *Lincolnshire*, 300 miles north-north-west of the centre at noon, had a stormy gale, with violent rain squalls, and the *Arratoon Apcar*, 350 miles north-east of the centre at noon, had very squally weather, with strong north-east winds. It is hence evident that the area of the strong winds and gales and of severe squalls had extended to a distance of at least 350 miles to the north-east and south-east of the centre.

November 4th.—Pressure had decreased over the whole of India. The fall was greatest in the Madras, Orissa and West Bengal coast districts, where it ranged from a tenth to a sixth of an inch. Skies were overcast in the North Madras coast districts, and were more clouded than hitherto in Bengal. Rain had, however, not yet commenced to fall in the coast districts of North Madras or in Orissa or Bengal.

The 8 A. M. observations at the coast stations indicate that there was a largish disturbance off the coast of the Circars and Ganjam, and that the centre was probably nearest to Vizagapatam, but they give no definite information of the intensity of the storm. The most noteworthy features of the observations were the very dry north-west winds at Cocanada and Vizagapatam, and the absence of rainfall in the outer area of the disturbance.

The 4 P.M. observations show that winds were unchanged in direction at these coast stations, but that their force was increasing rapidly at False Point and Saugor Island, due chiefly to the extension of the storm area during the day.

The storm did not affect the weather at Vizagapatam on the 4th to any important extent. Weather was unsettled and sea rough, but the north-west winds gave clear skies during the greater part of the day.

The meteorological data of this date furnished by the ships in the Bay are very unsatisfactory, as they do not enable the position of the centre to be exactly determined at any period during the day.

The marine data show that weather was very squally with strong southerly winds in the eastern half of the entrance to the Bay. It was fine and clear with light to moderate winds off the East Ceylon and Coromandel coasts and also over the greater part of the Andaman Sea. Weather was more or less disturbed over the centre of the Bay, and squally weather had now extended to the head of the Bay. The light vessels reported squalls and fresh E. N. E. winds in the morning. Weather was gloomy and skies overcast with north-east winds in South Bengal.

The only vessels which were within the storm area during the day were the S.S. *Waverly*, *Baria*, *Nubia* and *Meanatchy* and the Barque *Lady Agnes*. The S.S. *Japan* also experienced severe weather.

The *Baria*, judging from her barometric observations, was nearest the storm centre shortly after 8 P.M., when she had west-by-north winds, force 9. The winds increased for some time afterwards, and she had the strongest winds

from south-west, at 4 A.M. of the 5th, when their force was 11. The winds quickly moderated and at 8 A.M. she had fresh south-west winds, force 5.

The S.S. *Meanatchy* was crossing the Bay at this time between Gopalpur and Rangoon. She left Gopalpur on the evening of the 2nd. The Captain judged by the increasing winds, falling barometer and slight swell, that there was a cyclone to the south-east of the vessel, and he modified his course during the next 48 hours to avoid passing into the storm area.

She remained in the outer storm area during the day and experienced a moderate to strong gale until the evening, when, by running to the east, she passed into fine cloudy weather, with a moderate sea and strong breezes.

The S.S. *Nubia*, which was proceeding from Calcutta to London, passed through the eastern quadrant of the storm on the 4th. She had winds of force 6 to 7 and torrents of rain at times.

5th November.—Pressure had continued to give way over the whole of the Indian area, but the changes were small except in North Madras, the Central Provinces and North-Eastern India, where the fall was due to the advancing cyclone.

Skies were now overcast in Orissa, Chota Nagpur, South Bengal and Assam, and were partially clouded in the Gangetic Plain as far west as Allahabad. Rain was falling in South Bengal, Orissa and Chota Nagpur, but was light, except in Orissa immediately in front of the cyclonic storm, where the rainfall was excessive.

The 8 A.M. observations indicate that the cyclone on the morning of the 5th covered Ganjam and Orissa and the adjacent portion of the Bay area. The barometric readings and wind data at the coast stations showed that the storm was one of very considerable extent and intensity. The centre at 8 A.M. was about 10 miles east of Puri, and hence off the South Orissa coast. It was advancing in a north-easterly direction towards False Point.

The marine observations show that conditions were unchanged in the south of the Bay, where light to moderate winds obtained and weather was generally fine and cloudy. Occasional squalls were experienced, *e.g.*, the S. *Eurydice* in Lat. 11° N. and Long. 91°20′ E., had squally weather during the day and the S. *Joseph*, in Lat. 14°25′N. and Long. 91°50′ E., had squalls, with heavy rain, in the morning.

In the centre and north of the Bay cyclonic winds of indraught prevailed, and were of force 8 and upwards between the 18th and 21st parallels of latitude and to the west of the 90th meridian. The storm area was hence much larger than on the 2nd and 3rd, and had increased considerably in extent during the previous 24 hours, and at the same time the storm had not diminished in intensity.

The storm centre passed a little to the east of Gopalpur and Puri during

the morning and over False Point in the afternoon. It advanced about 25 miles to the east of Shortt's Island at the mouth of the Dhamrah river late in the evening. The following gives the accounts of the storm as experienced by the *Lady Agnes* and at these stations.

The *Lady Agnes* began to experience strong cyclonic winds on the morning of the 3rd, when she was at least 350 miles to the north of the centre. She drifted westwards during the day near the South Orissa coast. On the morning of the 4th, when she was about 200 miles to the north of the centre, she experienced a hard gale with hard squalls. The centre on the 4th recurved through north-north-west to north-north-east and rapidly approached the ship *Lady Agnes*. In the evening the wind had increased to a terrific gale from east-north-east. At 1 A.M. of the 5th, when the vessel was probably off the Ganjam coast east of Gopalpur, it was necessary to cut away the foremast. She was nearest the centre between 3 A.M. and 4 A.M., at which time she had hurricane winds with a tremendous sea. She was then probably not more than 15 or 20 miles from the centre. She was carried rapidly under the force of the winds and storm currents from the west to the south-east quadrant of the cyclone, and was gradually left behind on the morning of the 5th. Hence weather rapidly improved, and she had moderate winds and fine weather on the afternoon and evening of the 5th.

The ship *Lady Agnes* was nearest to the storm centre between 3 and 4 A.M. of the 5th, when she was in about Lat. 19°10′ N. and Long. 85°20′ E., and hence the storm centre, which was about 15 miles to the east, was in Lat. 19° 10′ N. and Long. 85° 35′ E. at that hour.

The following statement of the remarkable performance of the aneroid barometer on board the ship *Lady Agnes* deserves record :—

> "Our aneroid barometer did not register right, as it only fell from 30·00″ to 29·80″ before the full force of the cyclone burst upon us, and during the six hours during which it raged at its utmost violence and with hurricane force our aneroid did not fall any more, but rose gradually to 30 inches, as the fine weather set in."

The storm at Puri began at 10-30 P.M. of the 4th, and lasted until 1-30 P.M. of the 5th. During this period 13 inches of rain fell. The observer also states that the wind blew at the rate of 96 miles an hour at 9 P.M. of the 4th. This, however, is very doubtful. He also adds that it blew most heavily between 7 and 10 A.M. of the 5th, when it was utterly impossible to take readings of the anemometer on account of the violence of the wind. The anemometer was blown away shortly after 10 A.M. The wind was from north-east during the greater part of the storm and shifted rapidly to west-north-west between 7 A.M. and 10 A.M. Much damage was done to houses and many lives are reported to have been lost in the Chilka lake by the upsetting of boats.

The storm centre passed over False Point in the afternoon between 4-5 P.M.

and 4-45 P.M. Two series of observations are available, one taken by the observer at the light-house and the other by the Port Officer.

The central calm area passed over the light-house between 4-5 and 4-45 P.M., and hence lasted 40 minutes. As the storm was progressing at the rate of nearly 9 miles an hour, the greatest diameter in a north and south section was between 5 and 6 miles. The Port Office was just on the outer western edge of the calm centre. The Port Office bears north-north-east (*vide* Taylor's Directory) from the light-house.

The False Point observations throw light upon several interesting features of cyclones. The following are the most noteworthy points :—

First.—The passage of the calm central area over the light-house lasted more than half an hour, and hence afforded ample time to test the pressure and air motion conditions in and near the calm area. The calm lasted from 4-5 P.M. to 4-45 P.M. As described by the observer, the wind, which was blowing a moderate gale at 4 P.M., fell to a dead calm at 4-5 P.M. The transition was hence abrupt, but less so than is usually indicated by the remarks in the logs of ships that have passed through the central calm area of cyclones The dead calm was followed by light variable winds until 4-45 P.M., after which the wind increased very rapidly and was blowing with hurricane force at 5 P.M. These observations hence indicate that the transition from the central calm to the hurricane winds just outside the central calm area is less rapid than is usually supposed, and that the change is rapid and gradual, rather than abrupt and spasmodic.

The False Point Port Officer added the following remarks to the observations which he forwarded :—

"I would also beg to say that this has been one of the most severe cyclones that I have experienced during my long residence of 26½ years at False Point. The whole of the station, except the refuge building, is in ruins, but I am happy to say that no lives have been lost.

"The whole of the beacons marking the harbour have been blown away and Reddie Head Sand Spit has entirely disappeared. Yesterday afternoon I pulled across in my boat what used to be dry sand and found nothing less than 6 feet of water."

The keeper of the light-house on Shortt's Island at the entrance to the river Dhamrah (in Lat. 20°47′ N. and Long. 86°50′ E.) took a most valuable series of observations during the storm. The station was about 16 miles to the north of the centre when nearest to it about 8 P.M. and hence within the inner storm area of hurricane winds —

The following is his account of the weather on the 5th :—

November 5th.—From midnight to 6-0 A.M. the squalls continued with unabated force and frequency, but the rain was not heavy during this time. During a lull which occurred between 6-0 and 6-10 A.M. the wind shifted to E. by S., followed immediately by a terrific rain squall. At 6-40 A.M. wind backed to N-E. During the lulls after the squalls the wind veered to E-N-E

and backed to N-E. on the approach of the next squall. 8-0 A.M., no change in the frequency or violence of the squalls; blinding rain prevailing. Between 8-0 and 9-0 A.M., after the squalls the clouds broke to windward and after this the sky again became entirely overcast and squalls increased in violence; wind still unsteady. From 11-0 to 11-10 A.M. the sun shone brightly, the interval being between two squalls; afterwards the sky became overcast and very wild-looking, and squalls more violent with heavy rain. At noon I noticed that the sea-level had fallen about 4 feet in the space of about half an hour; no apparent change in the weather. From noon to 3-0 P.M. squalls one after the other in quick succession of terrific violence with hard rain. At 3-20 P.M. wind shifted to E. by S., squalls still most terrific. From 4-0 to 5-0 P.M. the appearance of the weather was most terribly wild; all persons took refuge in the light-house at this time. From 5-0 to 10-0 P.M. a hurricane from E-S-E., with incessant heavy rain and lightning; 10-10 P.M. weather suddenly moderated to fresh breeze, but gusty. At 10-50 P.M. the wind shifted to N., blowing a very strong gale, but gusty with light rain and lightning. Barometer rising rapidly and pumping very much. Midnight, no change.

6th November.—The various observations indicate that the centre had continued to recurve slowly during the night of the 5th, and at 8 A.M. of the 6th it was crossing the coast of the Sunderbunds some distance to the east of Saugor Island and marching in an east-north-east direction.

Skies were now overcast over the whole of Bengal and Assam and also in South Bihar and Chota Nagpur. They were partially clouded in North Bihar and the eastern districts of the North-Western Provinces, and were clear over the whole of North-Western and Central India. Very heavy rain had fallen in Orissa during the previous 24 hours.

The chart giving the 8 A.M. distribution of pressure of this day shows that the storm centre at that hour was due east of Saugor Island, at a distance of between 30 and 40 miles.

The observations appear to indicate that the storm was already beginning to break up. Strong winds were blowing at Saugor Island and Calcutta nearest to the centre. These stations occupied the same position at this time relative to the centre that Gopalpur had done about 24 hours previously. The winds at these stations at 8 A.M. were very much feebler than at Gopalpur, their velocity being not more than one-half or one-third that at Gopalpur on the previous morning, when it was nearest the centre. The winds at Barisal, Dacca and Jessore in East Bengal in the north-eastern quadrant, were comparatively feeble, and Barisal reported a calm at 8 A.M.

The disintegration of the storm proceeded rapidly during the day.

The 4 P.M. observations indicate that the centre was a little to the south-east of Dacca. They also show that the storm was fast filling up, and that it was now a very shallow diffused depression of little importance.

Light winds prevailed at Chittagong and Silchar and moderate winds at Dacca. Skies were overcast over the whole of Bengal, with the exception of the northern districts, and light to moderate rain was falling in South and East Bengal.

The storm centre at 8 A.M. was about 35 miles to the east of Saugor Island and at 4 P.M. was a little to the south-east of Dacca. As it had passed over False Point between 4 P.M. and 5 P.M of the preceding afternoon, it advanced across the north-west angle of the Bay during the night. The light vessels and pilot vessels and a number of vessels which had arrived at the Sandheads during the previous 48 hours, and were cruising about, waiting for the bad weather to pass away in order to obtain pilots and proceed up the river to Calcutta, were all involved in the storm during the night and experienced hurricane winds and a tremendous sea.

The P. V. *Coleroon*, which had passed through nearly every cyclonic storm of the previous 20 years, foundered during the night off the Orissa coast.

The storm centre passed over the F. L. V. *Canopus* at 2-30 A.M. of the 6th. She was stationed at the *Intermediate Station* (Latitude 21°14′ N. and Longitude 88°11′ E.) 30 miles to the S-S-E. of Saugor Island.

Captain Beahan describes the weather he experienced as follows :—

"The 5th commenced with a brisk easterly gale and high sea, but as the day advanced the wind increased in force, the sea became more confused, and the blinding heavy rain squalls more frequent. By 4 P. M. it was blowing a hard gale, wind veering from east to east-south-east in the squalls, and at 10 P. M. it had settled and remained steady at east till 2-30 A. M. on the 6th, when it suddenly fell calm, the calm lasting not more than from 3 to 4 minutes. At this time the wind shifted suddenly into the west-north-west and blew with terrific force. In all my experience at the Sandheads during the last 16 years, I have never seen anything like the heavy rain, thunder and lightning, terrific sea and force of the wind that we experienced in this storm.

"From 10 P. M. on the 5th to 3-30 A. M. on the 6th it was blowing with most terrific force and the sea very high and confused. At 2-20 A. M., just before the centre passed over us, the vessel heeled over to starboard, putting main and other hatches in the water. We then parted a 20-inch coir cable, and were driven from ou station. We remained in the above position, vessel heading east-south-east till 3-30 A. M. ; the terrific sea sweeping over us. When it moderated I brought the vessel up, and at daylight found myself near the South Channel, being 18 miles south-west off my station. I observed a number of wrecks of vessels floating about bottom up, and in pieces, and the sea covered with wreckage."

The storm centre also passed over the F. L. V. *Star* stationed at the *Lower Gasper Station*, Lat. 21° 26′ N., Long. 88° 6′ E., about 10 miles from the *Intermediate Light Ship*. The captain sent in the following report of the storm :—

5th.—"Wind easterly and squally. At 9 P.M. a very heavy squall from east, with torrents of rain (which may be taken as the commencement of the hurricane following a few hours after). Squalls increased in violence until midnight, by which time a terrific hurricane had developed itself with a dangerously heavy sea running.

6th.—"The hurricane continuing with unabated fury until 6 A.M., when sea and wind commenced to moderate. About 3 A.M. of the 6th the calm centre passed over the vessel, the calm lasting about 10 or 15 minutes, after which the wind flew into north veering to north-west. At 10-30 P.M. of the 5th the ship parted from her coir cable, but was brought up with the second anchor and 90 tons cable coir, after drifting off her station about 2½ miles."

The ship *Anne Main*, after passing through the eastern quadrant of the cyclone on the 3rd, advanced northwards towards the Hooghly and encountered the full strength of the storm on the night of the 5th and early morning

of the 6th. The following extract from her log shows fully the character of the weather she encountered on the night of the 5th :—

Date and hour.	Weather.	Date and hour.	Weather.
Noon . .	Wind freshening and coming in strong gusts and squalls of rain.	11 P.M. . . *concld.*	leeside under water. Ballast shifted. Squared the yards to ease the ship. Found it necessary to cut away the mizenmast and main-top gallant mast and all gear. Mizen lay across the rail doing much damage.
1 P.M. . .	Strong gale from south-east, sky having a wild and threatening appearance.		
6 P.M. . .	Very hard gale with heavy rain.	Midnight .	Hurricane seemed to reach its highest degree of violence; ship drifting at the mercy of the gale. During this terrific burst the ship lay over very dangerously with leeside under and deck full of water. Sea literally falling in heaps around us. Afterwards beginning to take off, barometer having fallen to 28·80″. First rise of barometer about midnight; afterwards going up rapidly.
8 P.M. . .	Wind increasing. Hurricane with terrific squalls of wind and blinding rain. Wind beginning to back to the east.		
11 P.M. . .	Blowing a whole hurricane with squalls of terrific force and blinding rain. Lightning flashing in sheets of vivid flame and much thunder. Wind abeam and ship unmanageable lying with		

7th November.—During the previous 24 hours pressure had increased generally in the Indian area by amounts not exceeding ·05″. In North Eastern India these changes had been supplemented by the changes due to the advance of the storm and to its gradual filling up. Pressure had hence increased very rapidly in South and West Bengal and Orissa and had fallen slightly in Assam, Cachar and Upper Burma.

The depression at 8 A.M. was in the Cachar district of Assam and adjacent districts, but it was now very slight and of little importance.

Winds were very light at all the stations in Assam and Upper Burma, and averaged only 2 miles an hour during the previous 24 hours at Silchar, Sibsagar and Kindat, and three out of the six stations reported calms. Hence, in the 24 hours preceding 8 A.M. of the 7th during which the storm had passed across the seaface of the Sunderbunds into the plains of South and East Bengal, the vigorous cyclonic circulation had been completely broken up and the winds in the residual depression were even below the normal winds of the season in strength at 8 A.M. of the 7th. This rapid disintegration of the storm appears to have been due to two causes :—

1st.—The decrease in the general strength of the southerly humid winds of indraught in the south and centre of the Bay, which had com-

menced at least 36 hours previously and was very marked on the morning of the 6th.

2nd.—The effect of the hills of Assam and East Bengal in breaking up the cyclonic circulation advancing towards the angle formed by them in the north-east of Cachar.

The breaking up of the storm accompanied a rapid clearing up of the skies during the night of the 6th.

Intensity of the storm as gauged by the maximum depression of the barometer.—The following give the lowest barometric readings actually observed in or near the calm central area on different dates :—

	Date.	Position with regard to calm centre.	Barometer corrected and reduced to sea-level and constant gravity.	Variation from normal of day.
			"	"
Port Blair . .	2nd—2 A.M.	9 miles from central area.	28·254	—1·55
	3 A.M.	5 miles from central area.	28·359	—1·43
Puri . . .	5th—6 A.M.	25 miles from central area.	29·068	—0·77
False Point Light-house . . .	Ditto—3·45 P.M.	2 miles in front of calm centre.	28·012	—1·83
False Point Port Office . . .	Ditto—5 P.M.	Just outside the calm centre.	28·190	—1·66
Shortt's Island .	Ditto—8 P.M.	25 miles north from calm centre.	29·028	—0·86
Intermediate station .	6th—2·0 A.M.	In calm centre.	28·670	—1·22
Lena . . .	Ditto—1·15 A.M.	In calm centre.	28·000?	—1·89
Lincolnshire . .	Ditto—2 A.M.	5 to 10 miles from calm centre.	28·860	—1·03
Japan . . .	Ditto—2·20 A.M.	20 to 30 miles from calm centre.	29·150	—0·78

A consideration of these facts and of the observed pressures at distances of 10 to 30 miles from the calm central area, appears to establish the following inferences :—

(1) From the morning of the 2nd (and probably from the afternoon of the 31st October) up to midnight of the 5th or 2 A.M. of the 6th the minimum pressure in or just outside of the calm area was less than 28·1 inches, and was very probably slightly below 27·75 inches on the 1st and 2nd.

(2) The maximum depression in and near the calm central area hence undoubtedly ranged between 1·6 inches and 1·83 inches during this period, and was very probably slightly greater than 2·1 inches on the 1st and 2nd.

(3) It would hence appear that the maximum barometer depression, and therefore the pressure conditions of the calm central area, were remarkably uniform during the whole of this period from the 31st to the afternoon of the 5th, including an interval of nearly 6 days; thus indicating a remarkable persistence and steadiness of the conditions of the central calm area and inner storm area, or core of the storm.

Intensity of the storm as measured by the magnitude of the steepest gradients in the storm area.—The unit of gradient adopted by European meteorologists is ·01 inch per 15 geographical miles. The mean pressure difference during the south-west monsoon period is barely ·3 inch over the Bay of Bengal between Lat. 7° N. and Lat. 22° N. This mean pressure difference over the Bay corresponds to a mean gradient of nearly ·5. The gradients of course vary in different parts of the Indian land and sea area during the south-west monsoon, but they probably rarely exceed 1 or 2, except in the neighbourhood of, or within any area affected by, a cyclonic storm of the rains. It may also be noted that gradients seldom exceed 5 to 10 in European cyclonic storms.

The following gives the steepest observed gradients in the Port Blair cyclone as determined by accurate observations taken at the two land observatories in its path:—

Station.	Interval.			Difference of pressure.	Gradients.
	Hour.		Hour.	Inch.	
Port Blair	1	to	2	·20 fall	67½
False Point Light-house	14	to	14-30	·372 „	112
	14-30	to	15	·302 „	91
	17	to	17-30	·306 rise	92
	17-30	to	18	·310 „	93
False Point Port Office	15	to	15-30	·200 fall	60
	15-30	to	15-45	·100 „	60
	15-45	to	16	·180 „	108
	17	to	17-30	·110 rise	33
	17-30	to	18	·270 „	81

If it be assumed that the lowest pressure at Port Blair was 27·75 inches and that it occurred between 2-20 to 2-35 A.M., this would give a fall of pressure of half an inch in a distance of 7 to 12 miles. The former would correspond to a gradient of nearly 110, agreeing closely with the observed gradients at False Point. It should also be noted that these are mean gradients based on observations taken at half or quarter hourly intervals; and hence

not the maximum gradients at any instant during any one of these intervals. It is almost certain that the steepest gradients exceeded 120.

The following conclusions respecting the steepest gradients in this cyclone are based on the previous data and the connected considerations :—

(1) The steepest horizontal gradients in the storm were in the front or advancing quadrant, and almost certainly exceeded 100, and probably slightly exceeded 110 during by far the greater part of the existence of the storm. These are the mean gradients based on observations taken at quarter or half-hour intervals, and it is possible that the steepest gradients may have been at least 25 per cent. greater, and may have exceeded 150.

(2) The steepest horizontal gradients observed in the western or retreating quadrant ranged between 80 and 100, and were about 20 per cent. smaller than the steepest gradients in the advancing quadrant.

(3) The maximum gradients in the inner storm area were almost certainly remarkably steady from the evening of the 1st and probably from the evening of the 31st until midnight of the 6th, and probably did not, under similar conditions of measurement, vary more than 10 per cent. during this interval.

(4) Hence the maximum gradients near the calm central area in this storm as well as the maximum barometric depression were remarkably steady and uniform during a period of at least six days.

The preceding data hence establish that the mean pressure in or just in front of the central calm area from midnight of the 31st to midnight of the 5th averaged 28·00 inches, the maximum depression averaged 1·9 inches, the maximum gradients in the advancing quadrant averaged 110, and in the retreating quadrant averaged 90. The variation in these elements during the whole period was almost certainly less than 20 per cent., and probably not more than 10 to 15 per cent.

Magnitude of the storm.—The calm central area when passing centrically over Port Blair and the barque *Safir* was nearly 5 miles in width in an easterly and westerly direction or in the then direction of advance of the storm. It passed centrically over False Point Light-house on the afternoon of the 5th, and its diameter in the direction of advance of the storm was slightly greater than 5 miles. Considering the character and phenomena of the storm during the whole of its existence and the remarkable permanence of the chief features of the storm during the greater part of its existence, it is almost certain that there was a well-defined calm central area from the afternoon of the 31st up to 3 or 4 A.M. of the 6th, and that it formed one of the more conspicuous and important features of the storm. Its diameter in the direction of advance of the storm was practically the same in length on the 5th as on the 2nd, the only days for which there are data that enable it to be approximately measured. It

is hence very probable that during the whole of the period from midnight of the 31st to that of the 5th the calm central area was practically unchanged in magnitude.

There are no data from which an estimate of the shape of the calm area of the storm at any stage can be directly inferred. It is, however, most probable that it was, like the inner storm area, oval or elliptical-shaped and that its greatest diameter was in the direction of the advance of the centre and approximately 5 miles in length.

The inner storm area or area of fierce and destructive winds (force 10 to 12) has been ascertained at several stages throughout the storm. It was probably about 60 miles in its longest diameter and 30 miles in the shortest diameter when crossing the Malayan Peninsula. When advancing over the South Andaman Island it was between 70 and 80 miles in length by 50 to 60 miles in breadth. The inner storm area appears to have taken between 8 and 9 hours in passing over False Point Light-house. The rate of advance of the storm at that time was nearly 10 miles an hour. The diameter of the inner storm area (in the direction of advance) was hence at that time probably between 80 and 90 miles.

The whole of the data strongly support the inference that the inner storm area was practically unchanged in shape and extent from the evening of the 31st to that of the 5th. It was almost certainly elliptical-shaped throughout, its largest diameter averaging 80 miles and shortest diameter (probably) 60 miles. The direction of its longest diameter coincided approximately with the direction of advance of the storm centre throughout its existence.

It is much more difficult to estimate the extent of the outer storm area. It is, however, certain in the present case that when the storm entered the Andaman Sea it did not affect the weather and winds to any considerable extent at distances of 100 miles to the north and south. As it advanced over the Bay the area of strong winds and squally to stormy weather increased largely in extent. The extension occurred chiefly in the eastern and southern quadrants, where the indraught to the cyclonic storm intensified the south-west monsoon humid winds. For example, on the 5th, winds of force 8 (moderate gale) were experienced at distances of at least 300 to 350 miles from the centre in these quadrants.

Hence the important inference that the calm central area and the inner storm area were almost unchanged in extent, and in several other characteristic features from the 1st to the 5th, but that a very considerable extension occurred during this period in the outer storm area. The extension was greatest and most marked in the eastern and southern quadrants, the quadrants into which the humid winds that maintained the storm were chiefly drawn.

Calm centre.—The features of the calm centre of the cyclone, as far as

they are indicated by the observations taken at False Point and Port Blair, have been fully described in the body of the report. The following gives a summary :—

(1) Pressure was lowest at some little distance in front of the calm area.

(2) Pressure was not quite uniform in the calm area but increased slightly in proceeding along the diameter coinciding with the direction of advance and in the opposite direction.

(3) The air was practically, if not absolutely, calm within the calm area proper.

(4) The transition from the hurricane winds in front to the central calm was not sudden, but gradual ; and similarly in the rear the transition from the calm to hurricane winds was not instantaneous, but gradual. This is fully established by the observations taken at the False Point Light-house.

(5) The observer at the False Point Light-house thus describes the appearance of the sky when the calm centre was passing over it. "The sky was covered with broken cloud, and there was a heavy bank to eastward."

(6) The mercury column did not pulsate in the calm area as it did outside of it in the area of hurricane winds and fierce gusts. The Light-house keeper at False Point states—

"I noticed that during the approach of the storm the pointer of the aneroid oscillated a good deal, jumping up and down fully one-tenth of an inch, and the same thing occurred when the storm was receding ; but during the time the centre was passing it remained quite steady. At one time during the approach of the storm the pointer went as low as 28·08" with the oscillation. I have noticed a slight oscillation of two or three hundredths of an inch in other cyclones, but never to such an extent as in this one."

Rainfall.—As the storm passed chiefly over a sea area, the data for determining the character and distribution of rainfall accompanying the storm are limited. The rainfall in the storm area whilst it was crossing the Bay of Bengal was of the usual torrential character. Captain Beahan, of the F. L. V. *Canopus* at the Intermediate station writes that the rain was heavier than he had experienced in any previous storm at the head of the Bay. The commander of the F. L. V. *Foam* states that the storm began at his station with a heavy squall and torrents of rain. The S. S. *Saint Regulus* had very heavy rain, the S. S. *Japan* continual heavy rain and the S. S. *Lincolnshire* terrific rain squalls.

It is not possible to deduce with certainty the character of the rainfall in different quadrants of the cyclone area. The evidence is, however, strongly in favour of the supposition that the rainfall was heaviest in the advancing quadrant. Puri is a striking example. The centre was 10 miles to the east of Puri at 8 A. M. of the 5th. During the previous 24 hours 13·61 inches of rain had fallen

and during the next 24 hours only 1·80 inches were received. Equally strong evidence is furnished by the rainfall at False Point, where 11·06 inches fell during the storm. The rainfall at False Point was heaviest and most intense between 2 P.M. and 4 P.M., and hence in the advancing quadrant.

The rainfall data of the storm hence support the following inferences :—

(1) The rainfall accompanying the storm was excessive and torrential in character whilst it was in full vigour.

(2) The rainfall diminished rapidly on the 6th whilst the storm was filling up, and practically ceased before the residual depression had disappeared.

(3) The rainfall was heaviest in the advancing quadrant, not only whilst the storm was fully developed, but also whilst it was filling up.

Strength of the winds in the inner storm area.—The winds were exceptionally violent in this cyclone. The anemometers and wind vanes were blown away at four observatories, *viz.*, Port Blair, False Point, Puri and Shortt's Island. The centre passed over the first two. Puri was about 10 miles from the centre when it was nearest to it and Shortt's Island 25 miles.

The following gives the greatest wind velocity as recorded by the anemometers at the stations in and near the calm central area during its progress :—

STATION.	Air movement in miles per hour.
Port Blair	111·5 miles, 4 A. M. of the 2nd.
Gopalpur	42 miles at 11 P. M, of the 4th.
Puri	96 „ „ 9 „ „ „
Shortt's Island	64 „ „ 4 „ „ 5th.
Saugor „	77 „ „ 5 A.M. „ 6th.

The velocity was determined in the cases of Puri, Shortt's Island and Saugor Island by means of observations of the anemometer taken at intervals of three minutes, and hence represents very approximately the velocity at the times of observation.

It is hence very probable, if not almost certain, that in the strongest blasts the air velocity was certainly not less than 120 miles per hour and may have been as much as 150 miles corresponding according to the usual formula to a horizontal pressure of about 90 lbs. per square foot on an obstacle. Assuming the known maximum gradients in this storm and using Ferrel's formula giving the relation between the baric gradient and air velocity in cyclones, we get a velocity of about 130 miles per hour.

Secondary whirls.—A noteworthy feature of this storm was the existence of small subsidiary whirls as part of the large general disturbance. There is some evidence of the existence for a short time of certainly two—and perhaps

of three—subsidiary whirls in this storm. They were observed in the following cases :—

(1) By the S.S. *Arratoon Apcar* on the 3rd, 300 miles to the south-east of the storm centre.

(2) At Gopalpur on the 5th.

(3) In the Hooghly near Saugor Island on the 5th.

The first is the most remarkable. The following gives the observations recorded in the log of the S.S. *Arratoon Apcar* on the 3rd :—

Hour.	Distance and bearing of vessel from centre.	Barometer, corrected.	Wind.		Weather remarks.
			Direction.	Force.	
		Inches.			
4 A. M.	385 miles N.N.E.	30·068	S.E.	5	Fresh breeze and fast rising sea, overcast and very hard squalls at times.
8 "	355 miles N.E. by N.	29·958	E.	6	Strong breeze and squally with rain and strong head sea.
Noon	340 Miles N.E.	·918	N.E.	8	Fresh gale with hard squalls with heavy rain, thick sea.
4 P. M.	345 miles N.E. by E.	30·068	N.E.	8	1 P.M. Fresh gales with heavy squalls and dangerous cross sea running. 1-30 P.M. Wind fell away to a calm for 3 minutes, after which the wind shifted about from north-east to west and finally settled back to north-east, and the gale resumed its force.
8 "	355 miles E.N.E.	·168	N.E.	9	Hard gale with squalls of hurricane force accompanied with heavy rain, thunder and lightning.
Midnight	374 miles E.N.E.	·068	E.	9	Hard gale continuing, the squalls coming as before in terrible force with rain, thunder and lightning.

Assuming the observations to be correct, and allowing for the ordinary or diurnal oscillation of the barometer, pressure fell ·15″ between 4 A.M. and noon and increased ·25″ between noon and 4 P.M. These changes cannot be explained by a movement of approach to or withdrawal from the centre in the storm area. It was clearly due to some additional disturbance. The character of this disturbance is shewn by the fact that the *Arratoon Apcar* had for a short time at noon calms and light winds and that the wind which was north-east before the calm shifted to west as she passed out of the calm. The wind at 4 P.M. returned to its previous abnormal direction with respect to the

distant cyclone centre, *viz.*, north-east, although the vessel was then nearly 350 miles to the north-east. She had a hard gale during the remainder of the day with squalls of hurricane force.

The only satisfactory explanation of the preceding weather and wind changes is that the *Arratoon Apcar* passed through a small whirl with an inner area of light and variable winds or calms. It might have been due to a succession of two squalls with an interval of feeble winds, but the barometric data and the shift of wind direction from north-east to west appear to be opposed to this explanation.

Subsidiary whirls in large cyclonic storms have, so far as I can ascertain, been observed in a few cases. One of the most noteworthy occurred in the Samoan hurricane of March 1889. The following extract from a report on that hurricane by the Marine Meteorologist, Hydrographic Office, United States, Navy Department, describes it :—

" It will be noted from the report of H. M. S. *Calliope* that that vessel when she steamed out of Apia Harbour on the 16th into the northerly gale experienced a gradual but steady rise of the barometer, as was naturally to be expected, but that on the forenoon of the 17th there was a decided fall (about ·30″), followed by a still more rapid rise (about ·50″). No such fall of the barometer is recorded in the reports from the vessels at Apia, nor do the shifts of wind help us much in accounting for it. The only hypothesis by which it can be even partially explained is that a secondary, or storm of small size, but considerable severity, passed close to the *Calliope* and between her and the islands to the southward, affecting her barometer, but not the others. There is, of course, nothing very improbable about this (although one would expect the shifts of wind to have been more marked), and the formation of this secondary moving along a track about south-east by east may be assumed to explain the recurve to the southward and south-westward on the 18th and 19th of the Samoan hurricane itself, and its movement towards the East Cape of New Zealand (if it did move that way.)"

Recurvature of storm.—The Port Blair cyclone during the first three or four days of its existence travelled in the ordinary direction of storms passing across the centre of the Bay in the month of November, *viz.*, west-north-west. When it had advanced as far as the centre of the Bay, it began to recurve to north. As it approached the west coast of the Bay it recurved more or less steadily on the 3rd, 4th and 5th, and the total recurvature of the storm was larger than in any storm in the Bay on record. Its track was N. 69° W. when it entered the Andaman Sea, and N. 55° E. when it passed into Bengal. The total recurvature during its passage across the Andaman Sea and Bay of Bengal was hence 124°. This occurred, as already stated, on the 3rd, 4th and 5th.

As invariably happens when a storm recurves in the Bay, the rate of advance decreased very considerably and varied to some extent with the amount of recurvature. The velocity of the storm centre, which averaged approximately 20 miles on the 31st, 1st and 2nd, decreased to 9 miles per hour on the 3rd and 4th, and increased slightly on the 5th and 6th to an average of 12 miles for the 24 hours preceding 8 A.M. of the 7th.

That recurvature should cause a decrease in the rate of advance of the storm is in accordance with ordinary mechanical principles. The general tendency of cyclonic storms in the Bay of Bengal is to advance in approximately straight tracks over the sea area. If they recurve, it is due to some obstruction or obstructive action, the conditions being such as to enable the storm to change its path without its rotatory motion being broken up. The higher portions of the East Ghâts in Ganjam and Vizagapatam frequently act as a barrier to storms advancing from the Bay. They form in these districts a mountain mass of considerable width, the higher elevations of which attain to heights of 5,000 and 6,000 feet. When a storm is advancing obliquely towards them, they cut off to some extent the indraught in the western quadrant. The indraught of the humid current in the eastern quadrant is practically maintained intact. In such cases (*i. e.*, when storms are advancing more or less obliquely to this part of the East Ghâts) they are usually deflected to the north and the centres recurve to an extent depending upon conditions of the storm itself or upon special or abnormal meteorological conditions obtaining at the time.

The following table gives data showing the amount of recurvature from the 2nd to the 6th and the velocity :—

Date.	Hour.	Direction.	Change in previous 24 hours.	Velocity.	Change in previous 24 hours.
				Miles.	Miles.
2nd . .	8 A.M.	N. 70° W.	—	450	—
3rd . .	"	N. 62° W.	8°	280	—170
4th . .	"	N. 42° W.	20°	220	—60
5th . .	"	N. 7° E.	49°	250	+30
6th . .	"	N. 43° E.	36°	230	—20

Track and rate of advance.—The following table gives the position and rate of advance of the storm centre at intervals during the existence of the storm from the 1st to the 6th November:—

Date.	Hour.	Place.	Position.		Distance passed over during interval.	Average rate of motion in miles per hour.
			Lat. N.	Long. E.		
			° ′	° ′	Miles.	
Nov. 1st .	1-30 A.M.	Chaiya	9 10	99 16	...	...
	3 „	Kapu	...	...	40(?)	...
	8 „	......	9 50	97 30	150	23·1(?)
„ 2nd .	2-30 „	Port Blair	11 40	92 40	330	17·8
	8 „	Mid-Bay	12 10	91 10	115	20·9
„ 3rd .	8 „	Ditto	14 10	87 20	275	11·5
„ 4th .	8 „	About 100 miles south-east of Vizagapatam.	16 25	85 5	220	9·2
„ 5th .	4 „	50 miles east of Gopalpur .	19 25	85 40	208	10·4
	8 „	15 miles east of Puri . .	19 45	86 5	35	8·8
	4-20 P.M.	False Point . . .	20 20	86 47	65	7·8
	9 „	20 miles east of Shortt's Island	20 45	87 15	32	6·9
„ 6th .	2 A.M.	Sandheads	21 15	87 51	48	9·6
	8 „	East of Saugor Island . .	21 45	88 45	70	11·6

THE CHITTAGONG CYCLONE OF OCTOBER 21st TO 24th, 1897.

Weather antecedent to the storm in the Bay.—The pressure conditions during the third week of October were such as usually initiate the so-called north-east monsoon rains in the Madras Presidency. The normal course is that pressure rises in North-Eastern India after a final burst of monsoon rains in that area, usually in the first or second week of October. The Bay is then converted into a closed area of slightly lower pressure than elsewhere. After a short period squally weather sets in over a part of this area, the depression intensifies and sometimes increases to a cyclonic storm. It is transferred westwards to the Madras coast and gives heavy rain for some time. The chief factor tending to prevent the development of the depression which formed in the Bay at this time was the excessive pressure prevailing in the northern half of the Peninsula, in part at least due to the advance of a cool dry wave across Northern and Central India. The chief feature of the disturbance was the heavy general rain it gave to North-Eastern India.

Pressure was very uniform over the whole of the Bay on the morning of the 20th.

The available data show that weather was fine with light winds and a smooth sea over the whole Bay area, including the Andamans.

Pressure gave way rapidly in the North Andaman Sea during the next 24 hours, and a shallow depression lay over that area at 8 A.M. of the 21st. It developed into a cyclone of great intensity. The following gives an account of this storm.

Origin of the storm.—As stated above, weather was fine with light winds over the south and east of the Bay on the 20th. According to newspaper accounts, weather had been stormy in the China Sea during the previous week or ten days. If this information be correct, it is probable that the rapid fall of pressure and appearance of a low pressure area suddenly and with little or no warning in the North Andaman Sea during the next 24 hours was due to the movement of a storm depression from the Gulf of Siam across the north of the Malay Peninsula. If this be the case, the storm was at this stage either of small extent or of very feeble intensity and the winds and weather at Tavoy, Mergui, and Port Blair were very slightly affected by it, and the strongest winds experienced by the vessels in the Andaman Sea was of force 4 to 5.

The observations indicate that there was at 8 A.M. of the 21st a depression in the North Andaman Sea, the centre of which was in about Lat. 14½° N. and Long. 96° E. Skies were clear or lightly clouded at 8 A.M. in Upper and Central Burma and overcast in Lower Burma, but no rain had fallen except in Tenasserim. Weather had changed rapidly in the Andaman Sea andwas squally with heavy rain at 8 A.M.

There are no data available giving direct information of the extent and intensity of the storm, but judging from the irregularity of the wind directions at the coast stations and the comparatively feeble winds actually recorded by vessels in the Bay and at the coast stations, it is very probable that at this stage the storm was of small extent as well as of moderate intensity. This is in agreement with the supposition that it had crossed the Tenasserim mountain range between Lat. 13° N. to Lat. 15° N. where it reaches an average elevation of about 4,000 feet.

A valuable series of observations was taken during the day by the observer at Diamond Island. These observations show most clearly the development of the storm during the day. The following give extracts from his weather remarks :—

21st—9 P.M.—"Wind increasing, sky overcast, frequent smart showers, sea rising."

11 P.M.—"Anemometer registered 2·5 miles in 3 minutes or 50 miles an hour. Sea tremendous. Rain falling in torrents frequently."

22nd—0-15 A.M.—"Weather cyclonic, wind blowing furiously. Anemometer registered

2·8 miles in 3 minutes or 56 miles an hour. Sea tremendous. Rain blinding and falling in torrents at frequent intervals."

0-30 A.M.—"Wind of cyclonic intensity. Anemometer registered 3·0 miles in 3 minutes or 60 miles an hour. Sea tremendous, with very heavy swell. Trees falling and thatch of outhouses being blown off."

0-45 A.M.—"Anemometer registered 2·9 miles in three minutes or 58 miles an hour. Sea tremendous. Drizzling rain."

0-55 A.M. to 1-15 A.M.—"Dead calm suddenly set in and lasted 20 minutes."

1-30 A.M.—"Wind started suddenly again, blowing violently at intervals of 2 to 3 minutes. Sea very rough."

2 A.M.—"Tremendous sea. Sky overcast. Drizzling rain followed by heavier rain and squalls. Wind seems to be shifting rapidly between north-north-east and east-south-east as wind vane is oscillating very rapidly between these two points. Anemometer registered 2·7 miles in three minutes or 54 miles an hour. Barometer 29·692" (corrected)."

2-30 A.M.—"Wind shifted to S.-S.-E. Tremendous swell coming from that direction. Wind varying between S.-S.-E. and E.-S.-E. Occasional heavy showers, otherwise drizzle."

3 A.M.—"Wind still blowing hard and seems to be steadying at S.-S.-E. Sea tremendous. Occasional showers."

The Diamond Island observations indicate that the storm centre passed to the south-west of that station between 8 P.M. of the 21st and 2 A.M. of the 22nd and was probably nearest to that station very shortly before 2 A.M. when it was probably not more than 40 or 50 miles to the south-west. The observations give very interesting information of the variations in the intensity of the winds during the storm at that station, more especially in the north-western quadrant. The highest recorded winds had a velocity of 60 miles per hour, and the lowest recorded pressure was 29·542" at 2 A.M. The observations suggest that the storm was developing rapidly and increasing in intensity at that time.

The observations when charted indicate that the storm centre at 8 A.M. of the 22nd was distant probably about 120 miles to the west-north-west of Diamond Island in Lat. 16½° N. and Long. 92½° E. The S.S. *Pentakota* was not far from the centre at 8 A.M. when she was in Lat. 16°33′ N. and Long. 93°9′ E. and proceeding on a north-west course to Calcutta. The strongest winds she experienced were of force 6. She had frequent heavy to hard squalls. She was then about 45 miles to the east of the centre.

The 8 A.M. data indicated that the weather at the coast stations in the north-east of the Bay was as yet very slightly affected by the storm.

Weather was cloudy with very light winds at Chittagong, Akyab, Saugor Island, and False Point. Every station in the north-east of the Bay reported much lightning, but no rain had fallen at Akyab or Chittagong.

The data indicate that the centre at 8 A.M. of the 23rd was probably a little to the west of the position of the S.S. *Maharani* at 8 A.M. or in about Lat. 18½° N. and Long. 91° E. She had violent winds of force 10 and blinding rain throughout the day and was nearest to the storm centre in the evening at about 6 or 7 P.M., at which hour a heavy confused sea prevailed. Weather was stormy

with terrific squalls and violent winds at 8 P.M. The weather began to moderate about midnight.

The 8 A.M. data, extracted from the logs of vessels in the storm area on this day, indicate that the storm centre at 8 A.M. of the 24th was in about Lat. 20½° N. and Long. 90¾° E. or Long. 91° E. All the vessels contributing information were at considerable distances to the south and west of the centre. Their observations indicate clearly the extension of the stormy weather in the north of the Bay. The S.S. *Maharani*, which was about 240 miles to the south-south-east of the storm centre, had winds of force 10 and terrific squalls. The *Karagola*, 100 miles north, had violent rain squalls. The S.S. *Pandua*, 150 miles further west, had S.-S.-W. winds, force 8, a high sea and violent squalls.

The storm was hence now one of great intensity, but the observations at the land stations continued to show that the inner storm area was of small extent. The storm centre passed over or near to Chittagong during the evening, as is shewn by the following observations taken at that station :—

Hour.	Barometer reduced to sea-level and constant gravity at Lat. 45°.	Wind. Direction.	Weather.
	"		
4-53 P.M.	29·231	E.-N.-E.	Cyclonic storm blowing, squalls heavy, occasionally with heavy rain.
5-47 „	·097	E.-N.-E.	Cyclone blowing furiously. Exceedingly heavy squalls, occasionally with heavy rain.
6-13 „	·018	E.-N.-E.	Severe cyclone blowing, large branches of trees falling and telegraph lines interrupted.
6-35 „	·018	E.-N.-E.	Severe cyclone, and squalls with heavy rain and lightning.
6-56 „	28·817	N.	Do. Wind more north.
7-20 „	·747	N.	Do. Wind tending to E. Heavy rain, lightning, and hail.
7-44 „	·680	N.-E.	Do. Terrific squalls occasionally with heavy rain and lightning.
8-40 „	·799	N.-N.-W.	Do. Wind tending N.-W.
9-28 „	29·120	N.-W.	Cyclone considerably moderated, wind light and occasional squalls and very heavy rain.

The storm centre as shown by these observations passed over or near to the Chittagong observatory between 7-45 P.M. and 8 P.M. Hurricane winds prevailed in the inner storm area and caused great destruction of property and crops in the belt over which it passed. Pressure at the storm centre was at least 1·2 inches below the normal. As the storm approached the coast about

the time of high water, the storm wave which accompanied it was of destructive violence, and overflowed the low grounds in the Islands of Kutubdia, Matarbari, and Moiskhal and the low coast districts between Chittagong and Ramree.

Heavy rain fell during the 24 hours preceding 8 A.M. of the 25th in a part of the Chittagong district and the South Lushai Hills. The falls in several cases varied between 7 and 10 inches.

The Superintendent of the South Lushai Hills reports that it began to blow hard at 9 P.M., and by 10 P.M., there was a hurricane accompanied by pelting rain. The storm abated at 12-30 A.M., having in the meantime made great havoc in the buildings and trees.

Track of the storm.—The following table gives data showing the position and average rate of movement of the storm centre from the 21st to the 24th :—

Date.	Position of centre at 8 A.M.				Distance travelled during interval.	Average hourly rate of motion during interval.
	Lat. N.		Long. E.			
	°	′	°	′	Miles.	Miles.
21st	14	30	96	0	...	...
22nd	16	30	92	30	275	11½
23rd	18	30	91	0	170	7
24th	20	30	90	45	142	6

The storm wave.—The main force of the cyclone on the 24th was confined to a strip, extending from about 14 miles above Chittagong town on the north to a point some 4 miles below Cox's Bazar on the south, about 70 miles wide in all. North and south of this strip little damage was done, but within it the force of the cyclone was very great. The portions swamped by the storm wave consisted of the islands of Kutubdia and Matarbari and a strip of low land on the main land opposite. The area of the tracts affected was about 225 square miles ; of this some 32 miles should be deducted for mangrove jungle, leaving 193 miles of cultivated lands affected.

The storm was in several respects similar to the storm which passed over and wrecked Port Blair in November 1891. Like that storm it crossed the Malay Peninsula from the Gulf of Siam, and was of small extent but of great intensity, the winds in the inner storm area being of hurricane force. It passed by an east-north-east path across the north of the Andaman Sea through the Preparis North Channel into the Bay of Bengal and thence recurved through north-west to north and finally to north-north-east passing across the Chitta-

gong Coast as a small storm of great violence. The storm winds and rain caused great destruction of crops and property and the storm wave flooded the low coast districts causing the death of at least 7,000 people.

The greatest part of the storm and the advance of the storm wave took place in the dark ; and this circumstance materially increased the loss of life. According to a statement derived from imperfect police reports, the number of deaths reported was 7,401.

The Collector, after visiting the littoral tracts, says, that in many cases the village sites had been obliterated, and everything swept away. In these villages the mortality among women and children was very great. In the case of four villages which he visited he says that the few survivors had lost everything. They were clothed with rags found in the jungles, and were living in rough huts made out of jungle and the fragments of their ruined houses. They were eating the half-ripened rice from their fields and drinking brackish water.

The estimate of the number of deaths given above is almost certainly considerably below the actual which was probably 10,000 or 12,000 at the very least; a disproportionate number of these were no doubt women and children who had not the strength and activity to take refuge in trees.

The destruction of cattle was also on a very large scale, but the measure of the loss is at present impossible to estimate. In one village in which there were formerly 3,000 head, only 90 remained after the storm.

CHAPTER V.

BRIEF SUMMARY GIVING PRACTICAL HINTS TO SAILORS RESPECTING CYCLONIC STORMS IN THE BAY OF BENGAL.

In consequence of certain actions the air is frequently set into motion over a part or the whole of the Bay of Bengal in the manner which is usually described as cyclonic circulation. In an area over which a cyclonic circulation is for the time established the barometer falls from the outskirts to a point which is roughly speaking in the middle of the area. This part is called the centre of the cyclonic circulation. The air in a cyclonic circulation moves in a somewhat complex manner. It not only moves round the centre, but is also drawn in towards the centre, and when it approaches the centre is also carried upwards. The path of the air (and hence the direction of the winds) is not in circles, but is a species of spiral in which it approaches the centre as it moves round. The air moves round the centre in an invariable manner in each Hemisphere. In the Northern Hemisphere it moves in the following manner—south, east, north, west, or against the sun. The revolving motion is also sometimes described as counterclock-wise, or as the same kind of turning or twisting motion which an ordinary screw makes when being withdrawn.

The weather in a cyclonic circulation in the Bay is usually cloudy and rainy, and sometimes stormy. There is a strong tendency at certain seasons of the year for any cyclonic circulation which has been established in the Bay to increase in extent and intensity, in which case it may give stormy weather and hurricane winds in the inner portion of the cyclonic circulation.

When the winds in any part of a cyclonic circulation are of force 8 to 10 and do not exceed force 10 in any part, that part of the cyclonic circulation is called a cyclonic storm. If the winds in any portion of it are of hurricane force, (11 or 12), it is called a cyclone.

The use of the terms cyclonic storms and cyclone in this manner was suggested by Mr. Blanford and is adopted in this book as most appropriate. A cyclonic storm or cyclone is hence that part of a cyclonic circulation in which winds are of force 8 and upwards, and is always of very much smaller extent than the cyclonic circulation of which it forms the inner part. Cyclonic circulations, and therefore also cyclonic storms, vary greatly in intensity and size. The intensity of a cyclonic storm or cyclone is usually measured by the amount through which the barometer falls in passing from the outskirts of the cyclonic circulation to the storm centre, and sometimes by the force of the strongest winds. The first is, on the whole, the best measure.

Cyclonic circulations are sometimes of vast extent, covering a whole continent or an extensive oceanic area. In the Bay of Bengal cyclonic storms or cy-

clones are rarely more than 500 or 600 miles in diameter, and are frequently less than 100 or 150 miles in diameter.

The largest cyclones usually form slowly in the centre of the Bay (or to the west or north-west of the Andamans), and advance by the longest path before reaching land, *i., e.* to the north or towards the Bengal Coast.

Cyclones usually increase in intensity as they advance from their birthplace to the coast, and are usually most powerful and dangerous just before reaching land.

Hence large storms in the Bay of Bengal are of two kinds—

1st.—Those in which there is a calm centre, and inner storm area of hurricane winds, and an outer storm area of violent winds. These are termed in the present book 'cyclones'.

2nd.—Those in which there is no well-defined calm central area, and in which the winds do not exceed force 10 or 11, and the barometric fall at the centre is not large, the barometer rarely falling below 29·00″. These storms are termed in the present book 'cyclonic storms'.

By this notation the term 'cyclone' is restricted to the fiercest and most dangerous storms of Tropical seas, as was probably intended by Piddington, who introduced the word.

The Bay of Bengal is almost absolutely free from cyclonic storms or cyclones in the months of January, February, and March. They are of rare occurrence in the month of April.

Cyclonic storms may occur at any time from the beginning of April to the end of December, but are most frequent during the months of July, August, and September.

Cyclones are of occasional occurrence during two periods, known as the transition periods, which precede and follow the general prevalence of the south-west monsoon over India.

The first period extends from the beginning of May to the middle of June, and the second from the middle of September to the middle or end of December.

The largest and fiercest cyclones are met with in the months of October and November.

Indications of the formation or approach of a Cyclonic Storm in the Bay during the South-West Monsoon period from the 15th of June to the 15th of September.

The first indications, or the chief features, of the weather in the north of the Bay antecedent to these storms are—

(1) Before a storm of this class commences to form the barometer is usually more or less above the normal height of the period,

sometimes as much as two-tenths of an inch, in the north of the Bay.

(2) Winds are very light and variable at the head of the Bay and frequently shift round to north and north-east at Saugor Island and False Point. At sea (in the north-west of the Bay) the chief feature of the winds is their lightness and variability, thus contrasting greatly with the normal winds of the South-West Monsoon.

(3) Weather is usually fine with passing clouds, but more or less unpleasant and oppressive in consequence of the great dampness and stillness of the atmosphere. The atmosphere is frequently very clear. The rains are practically suspended in Bengal for the time being, and usually little rain beyond light local showers falls at the head of the Bay.

(4) Light to moderate south-west winds prevail in the south and centre of the Bay, with perhaps occasional rain-squalls. There is a strong tendency for the winds and squalls to increase in force.

Under such conditions cyclonic storms frequently form near the head of the Bay. The majority of the storms are feeble and of no great importance to sailors. The indications of the existence of a severe storm of this class are as follows:—

(1) A strong and squally monsoon over the south and centre of the Bay.

(2) Rapid increase in the strength of the south-west and south winds in approaching the head of the Bay. The winds in the southerly and south-easterly quadrants of the storm area are sometimes almost of hurricane force.

(3) A rapid succession of severe rain-squalls, increasing in intensity and frequency as the storm area in the north of the Bay is approached and entered.

(4) Comparatively light cyclonic winds in the north-west and south-west quadrants, even at moderate distances from the centre. These give no indication of the strength of the winds in the opposite quadrants.

(5) As these storms occur in the midst of the South-West Monsoon and usually form close to shore near the head of the Bay, the indications given by sky, swell, etc., as to the position of the centre, etc., are usually very feeble, and of little use.

The rules for obtaining the bearing of the centre and track of a cyclonic storm of this class are the same as for the cyclones of the transition periods. As they almost invariably form near the head of the Bay and move westward across the Orissa coast or northward into Central Bengal, past experience is especially useful in indicating their probable path in any month.

INDICATIONS OF THE FORMATION OR APPROACH OF A CYCLONE IN THE BAY DURING THE MONTH OF MAY, THE FIRST HALF OF JUNE, THE LAST HALF OF SEPTEMBER, AND THE MONTHS OF OCTOBER, NOVEMBER, AND DECEMBER.

The following are the chief features of the weather which immediately precede the formation of cyclones and cyclonic storms in the Bay in the months of May, October, November, and December:—

(1) Pressure is very uniform over the greater part of the Bay, more especially the centre, and in the Peninsula and the greater part of Northern India. The barometer is hence very steady and generally from one to two-tenths of an inch higher than usual.

(2) Winds are very light and variable in the centre of the Bay. Light steady north-east winds prevail in Bengal and at the head of the Bay.

(3) Fine clear weather with a smooth sea, and a very transparent atmosphere usually obtain in the north and centre of the Bay.

(4) South-west winds prevail over the south of the Bay, tending to increase in strength and give rain-squalls.

If the south-west winds increase in strength and pour large supplies of aqueous vapour into the area of light, variable winds in the centre or north of the Bay, they may give rise to a disturbance or cyclonic circulation, which will under favourable circumstances, develop rapidly into a cyclonic storm or çyclone.

When a cyclone has formed, and begins to move northwards or westwards, the following changes occur, which are hence important indications of the existence of a cyclone in the Bay:—

(1) The barometer begins to fall in the Bay, at first very slowly, and afterwards more and more quickly.

(2) The south-west winds in the south of the Bay increase in strength, the weather becomes more squally and unsettled in that area and cloud increases in amount and shows, by its increasing movement, indraught to a central or cyclonic disturbance.

(3) In the area to the north of west of the srorm area which has formed the sky becomes less clear and transparent, and a veil of light cirrus appears and extends northwards. This veil thickens very gradually, and frequently gives rise to conspicuous halos round the sun or moon. These clouds at such a time frequently show very dark or vivid bright red colours at sunrise or sunset.

(4) Strato-cirrus or cirro-stratus clouds shortly after begin to appear below the cirrus clouds, and increase and extend outwards (*i.e.*, northwards and westwards). The humidity of the air increases,

the weather becomes more sultry and oppressive and the wind begins to shift, and becomes steadier, and increases very slowly in force, in the north of the Bay.

(5) Shortly afterwards the first indications of the cloud bank are seen low down on the horizon. Its position is sometimes first shown at night by frequent, and in some cases almost continuous, lightning which is seen by reflection from distant clouds. It is at this time so far off that no thunder is heard. This lightning and the cloud bank may be seen sometimes as much as 48 to 72 hours before the approach of the storm.

(6) The winds shortly after begin to freshen, cumulus and nimbus clouds appear on the horizon and gradually extend and cover the sky, and light drizzling rain begins to fall. Passing squalls then begin to come up, and the wind becomes more and more gusty. The squalls increase in intensity and frequency as the storm approaches.

(7) The storm gives rise to great agitation of the water surface which passes from it as swell travelling rapidly outwards in all directions. In the north and west, where the winds are light, it is not mixed with swell due to the wind. Hence frequently one of the earliest indications at the head of the Bay of the existence of a cyclonic storm to the south is the setting in of an increasing heavy swell.

It should be carefully noted that (3), (4), (5), and (6) are the indications in front of an advancing cyclone, and hence are observed in the north and west of the Bay, and more especially at the head of the Bay. In the south of the Bay (or in the rear of the storm) the indications are different and are given in (1) and (2). These are the prevalence of strong squally south-west winds, the passage of frequent rain-squalls, increasing in frequency and force, (more especially if the vessel is proceeding northwards) with constant thick cloud, gloomy weather and a heavy southerly or south-westerly swell. Occasionally the lower and middle clouds (more especially on moonlight nights) may be observed scudding with great rapidity northwards. As soon as the continued fall of the barometer, the increasing frequency and strength of the squalls, etc., indicate to the mariner in the Bay of Bengal that he is approaching a cyclonic storm, he should proceed to determine the bearing and course of the centre.

Bearing of the storm centre.—This is, on the whole, most easily determined to the north and west of the centre, or in the advancing semicircle. The following are occasional useful indications :—

(1) When the sky commences to cloud over with cirrus, the veil of this cloud usually appears most dense in a particular part of the hori-

zon. It also shows occasionally very dark red tints at sunset and sunrise. This cirrus forms a kind of misty mantle which overlies the storm or hurricane cloud mass, and its direction is sometimes the first indication of the existence and general bearing of the cyclonic storm.

(2) When cirro-stratus clouds begin to show below the cirrus they frequently appear to diverge or radiate from a particular part of the horizon. In this case the focus or point of radiation or divergence corresponds nearly with the bearing of the centre.

(3) The direction of the centre of the cloud bank or of the lightning, which occurs almost continuously as soon as it begins to be visible, gives a very approximate estimate of the bearing of the cyclone. The cloud bank of a cyclone is easily distinguishable from all other cloud masses by its fixity of position and form. It retains its shape and position unchanged for hours, and it is only when the storm is in the immediate neighbourhood that it loses its remarkable appearance. As it approaches masses of clouds are seen to be torn from it.

(4) The direction of the swell which is produced by, and passes out from, the distant storm, gives in many cases, a fair indication of the direction of the distant storm. To the south of the storm the swell passing out from the storm and the swell due to the strong southerly winds feeding into the storm give rise to a heavy cross swell. This is probably an almost unfailing indication of a cyclonic storm to the north.

These indications it should be noted are rarely observable to the south or east of the storm for obvious reasons. For example, the third indication (*viz.*, that of the cloud bank) is useless to the south of the storm centre, as the skies are more or less heavily clouded, and it is only under exceptional circumstances that the dense fixed cloud mass of the cyclonic storm can be perceived in the distant horizon.

The movement of the squalls in the case of the West India hurricanes (and probably in the larger cyclones of the Bay) is said to be at first from the cloud bank and diverging from it. The cumulus clouds of these squalls rise towards the zenith, spreading and covering the sky. The base of the cloud soon forms above the horizon the dark band characteristic of an approaching squall. With this cloud comes the rain when the wind freshens and veers to the right. Later, the squalls arise from the extreme portion of the cloud bank and follow the general movement of rotation of the meteor. If the scud above the cloud bank be noticed, it will be seen that it flies nearly parallel to it, so

that an observer looking to the cloud bank sees it crossing from left to right. The lower clouds in the interior of the hurricane generally fly in directions to the right of the wind and nearly perpendicular to the bearing of the centre. It may also be noted that a squall frequently ushers in a shift of wind, and that the wind during a squall is almost invariably to the right of that prevailing previous to the squall.

The previous indications are useful in giving a rough approximation of the bearing of the centre or in confirming the conclusion derived from the use of the following rule :—

The bearing of the storm centre from any point within the storm area (i.e., *area in which the winds are cyclonic in direction or are due to the cyclonic storm only*) *is at once obtained by observing accurately the direction of the wind and employing the table in page 194*, which is based on the rule that "*to determine the bearing of the centre at any position within a cyclonic storm in the Bay of Bengal, face the wind exactly, and the centre is usually between 10 and 11 points to the right hand* (*and on the average almost exactly 10½ points*)."

The sailor should remember this is the best approximation possible based on previous experience, and that it may be out really or apparently to the extent of a point in each direction, more especially in the north-west angle of the Bay, when a storm is approaching.

Dangerous and manageable semicircles and advancing and retreating semicircles.—The storm area is divided into two parts in two ways. Sailors frequently have been led to consider it as divided into two parts or semicircles by the track of the centre. That to the right of the track is termed the dangerous semicircle, because the cyclonic winds and currents tend to carry ships round and place them in front of the advancing centre, or in the most disadvantageous and dangerous position with respect to the storm. In the open sea it is the semicircle in which the maximum effort is required in order to avoid these dangers. The semicircle to the left of the track is called the manageable circle because the winds of the storm can be utilized to run away from the inner storm area and centre. *This is usually done by running with the wind several points on the starboard quarter or even a beam.*

A better division of the storm area (which is oval, and not circular in shape) in the case of cyclones in the Bay of Bengal, is by a line through the centre at right angles to the track, which usually divides the storm area into two halves of slightly different size. In the front half the barometer is falling and in the rear half it is rising. The line chosen separates these two portions or areas of the cyclonic disturbance, and hence divides or marks off at each instant all the places at which the barometer has fallen in consequence of the approach of the storm from that in which it is rising or beginning to rise. It is hence called

the trough of the storm. The half in front may be called the advancing semicircle and the half in rear the retreating semicircle. When the character of the storms in the Bay of Bengal and the character and lie of the coast, etc., are taken into account, it will be seen that the right-hand half of the advancing semicircle is by far the most dangerous portion of a cyclonic storm. This, which may be named the right advancing quadrant, is that portion of a cyclone which vessels leaving the Hooghly during a storm would pass into, in the case of the great majority of storms in the Bay, *i.e.*, those which advance to the Orissa and Circars Coast.

It may also be noted that the least dangerous quadrant in the storms which advance to any pertion of the north or west coast is the left advancing quadrant.

Position of the observer relative to the storm track.—If the bearing of the centre remains the same for some time (due to the centre advancing directly to the observer) this will be shown by the barometer falling and the wind increasing in strength, whilst its general direction remains unchanged (although it may shift for a short time in squalls). If the observer be in the storm area to the right or left of the track the wind will shift as the storm advances towards and past him. If the observe be not in the dangerous semicircle (as defined above) the wind veers or shifts with the sun through north, east, south and west, and if it shifts in this manner the observer is to the right of the track. In the manageable semicircle the wind backs or shifts against the sun, or through north, west, south to east, and if the wind shifts in this manner the observer is to the left of the track or in the manageable semicircle.

Direction of the track or course of the cyclone centre.—It is always desirable that the probable track as well as the bearing of the centre of a cyclone should be determined as early as possible in order to keep as far away from the inner storm area and to bear away from it if the vessel be approaching it. The transition from the outer to the inner storm area is always comparatively sudden, and if the sailor delay in taking stock of the storm he may find himself involved in the inner storm area before he is prepared and when it is too late to do anything. Hence, shortly after the sailor is certain he is involved in the outskirts of a cyclonic storm and is probably passing inwards towards the centre and the wind direction has informed him in which semicircle and quadrant of the storm he is, he should lie-to for some time and see whether there is any permanent shift of wind. If he be in the south or south-east portions of the cyclonic storm in which strong squally winds extend to very considerable distances from the storm, it is probable he will observe no permanent change of wind even if he lies-to for some hours, and in that case he may conclude he is at a considerable distance to the south. He should, if advancing up the Bay, either proceed slowly northwards or only take advantage

of the southerly winds in the easterly quadrant by keeping well to the east of the storm centre, and should only adopt that course if he be quite certain the storm is either not a large one or if it is a cyclone that it is advancing westwards and there is no chance of its recurving eastwards near the head of the Bay.

If he be in any of the other quadrants of the storm area, and more especially if in the right advancing quadrant, he should lie-to until he observes a shift of wind and note carefully the weather during this interval. A reference to the table in pages 201-2 will give him at a glance approximately the direction of the path or track of the centre. The directions in that table are only given to sixteen points, and are not intended to be assumed as exact. It is believed the table gives sufficiently nearly for the practical use of the sailor, the track of a cyclone in any case which he is likely to meet with.

It may be noted that there is no simple or satisfactory rule for determining approximately the distance of the centre of a cyclone by means of single observations such as can be taken on board ship.

The inner storm area of the intense cyclones of the Bay of Bengal is probably never less than 80 to 100 miles in diameter or greater than 400 or 500 miles. The rate at which the barometer falls, the rapidity with which the wind shifts, together with the force of the wind, and the swell and sky indications will usually tell the sailor whether a cyclone he meets with is a small or a large one and whether he is approaching or entering the inner storm area or is still well outside of it, etc. Combining these facts with the above statement of the limiting magnitudes of the inner storm area of cyclones, he will be able to estimate approximately at what distance he is from the centre.

No satisfactory rule can be given enabling him to decide whether a cyclonic storm he is entering has an inner storm area of hurricane winds or not, and still less at what distance its outer edge may be from him. As already stated the time of the year, the swell, sky appearances, etc., afford some indication. The only safe rule is to assume that any cyclonic storm in the May or October transition periods (*i.e.* from 1st May to 15th June and from 15th September to 15th December) may be a cyclone and to take precautions accordingly.

Usual tracks and probability of occurrence of cyclones and cyclonic storms in different months in the Bay of Bengal.—The following gives a brief summary of what is known from the experience of past years accumulated by the India and Bengal Meteorological Departments of the distribution of storms, month by month, in the Bay of Bengal.

January, February and March.—Cyclones or cyclonic storms are almost unknown in the Bay of Bengal in these months, and only occur under very exceptional circumstances and at very distant intervals.

April.—Cyclonic storms are of comparatively rare occurrence in the Bay of Bengal in April. They form either in the south of the Bay or in the

Andaman Sea. Those which form in the Bay proper are generated to the west of the Nicobars or Andamans, and march (in at least three cases out of four) in a west or west-north-west direction to the Ceylon or Coromandel Coast. Those which originate in the Andaman Sea march northward to the Lower Pegu Coast. Storms are somewhat less probable in this month in the Andaman Sea than in the Bay of Bengal.

May.—Cyclonic storms are of comparatively frequent occurrence in the Bay during May (about two every three years). If they originate in the first fortnight of the month, the chances are about three or four to one they will march in a westerly direction to the Coromandel coast; but if during the latter half of the month the chances are three or four to one they will march northwards to the head of the Bay. It is also about an even chance that a storm forming in this month will be of great intensity (*i. e.*, a cyclone).

June.—Cyclonic storms are of frequent occurrence in the north of the Bay in June. They usually form to the north of the 19° parallel of latitude, or quite at the head of the Bay. One or two such storms may be expected every year. It is an even chance whether they pass in some northerly direction into Bengal or in some westerly direction across Orissa. Their chief feature is the strong westerly or south-westerly winds or gales in their southern quadrants. It should also be noted that two out of three advance across the north-west angle of the Bay immediately to the south of the entrance to the Hooghly, and hence they are very trying to shipping leaving the Hooghly at such times.

July.—In July storms only occur in the north of the Bay. They are of comparatively frequent occurrence, an average of two or three occurring in every year. They usually march in a west or north-north-west direction across the north-west angle of the Bay to the Orissa coast. The chances that a storm forming at this time will march in that direction are about 10 to 1. These storms are frequently feeble, but in about one case out of two they give rise to strong westerly and south-westerly gales at the head of the Bay, in which the force of the winds exceeds 8. As they almost invariably cross the north-west angle of the Bay, and hence advance across the track of vessels leaving the Hooghly, outward-bound vessels, unless fully prepared to encounter a severe storm of this kind, should not leave the river Hooghly when the storm signals are hoisted, and should remain in the river until the lowering of the signals.

August.—Cyclonic storms are almost of as frequent occurrence in August as in July. Five out of every six form to the north of latitude 19° N. Hence the chief feature of the storms of August is the occurrence of strong westerly and south-westerly gales at the head of the Bay, and the shift of wind is rarely large enough to indicate their cyclonic character except in the north-west angle of the Bay. The storms of the month occasionally advance northwards across the Bengal coast, but most frequently in a west or west-north-west direction

across the Orissa or Ganjam coast. The chances based on previous experience that a storm which forms in the month will advance in a westerly or west-north-westerly direction are four to one, and that it will advance north into Bengal are one to four. As the majority of these storms advance across the track of vessels leaving the Hooghly, captains of vessels about to proceed to sea from Calcutta when the signals are hoisted should, unless they are prepared to encounter strong winds and a very heavy sea, remain in the river until the storm has advanced landwards.

September.—Cyclonic storms are about as frequent in the Bay during September as in July and August, an average of two occurring every year. These cyclonic storms, however, form, as a rule, further south than in the previous two months, but usually to the north of latitude 17° N. The chances are four to one that the centre of a storm which forms in September will advance in a westerly direction to the north-west coast of the Bay between Balasore and Cocanada. About one storm out of five advances in a northerly direction into Bengal. The great majority of these storms are of small intensity, and resemble the storms of July and August in general character and in the strength of the westerly and south-westerly winds (as compared with the north-easterly and northerly winds). Under exceptional conditions, the chief of which appears to be the earlier retreat of the south-west monsoon current than usual from Northern India, these storms are of great intensity and violence, and accompanied with hurricane winds. Hence cyclones are of very occasional occurrence in September, and are most probable in the last fortnight. They form in the centre of the Bay and the chances are about equal that they will advance in a north-west direction to the West Bengal or Orissa coast, or in a westerly direction to the coast of the Circars.

October.—Cyclonic storms occur slightly less frequently in the Bay in October than during any of the four preceding months (an average of about one yearly). They are of rare occurrence in the Andaman Sea, and rarely, if ever, form to the north of latitude 20°N. They may originate in any other part of the Bay, but form most frequently in the centre of the Bay between the Andamans and the coast of the Circars and the North Coromandel coast. If a storm forms in this month, the chances are probably about one to two that it will develop into a severe cyclone. The chances are about even that if a storm is generated in this month it will advance westwards to the coast of the Circars, and if it does so, the chances are also about even that it is a feeble or a severe storm, or in other words a cyclonic storm or a cyclone. The chances are about one to three that if a storm forms in this month it will advance northwards to Bengal or Orissa, and, if it does, the chances that it will be a severe storm or a cyclone are at least two to one. The chances that if a storm forms it will

advance to the Madras coast south of Gopalpur are also about one to two, but if it does, the chances that it will be a severe storm are probably about even.

November.—Cyclones may form in any part of the Bay and Andaman Sea to the south of latitude 16°N. in the month of November. Three out of four storms which originate in this month form in or to the south of latitude 12° N. At least one storm may be expected every year in this month. The chances that a storm in November will be a cyclone are about two to one. If a storm forms, the chances that it will advance to the Coromandel coast are even. About one storm out of four that form advances to the coast of East Bengal or of Arakan. The part of the Bay which is most free from cyclonic storms in this month is the north-west angle of the Bay and the coast from Saugor Island to Vizagapatam. On the other hand, the north-east coast of the Bay is more liable to cyclones in this month than in any other month of the year.

December.—Storms are of comparatively rare occurrence in the month of December, and only two storms are known to have formed in the Bay during the present century after the 15th of the month. No storm has been known to form in the Andaman Sea in this month. Storms occasionally form in the south or south-west of the Bay of Bengal between the Ceylon coast and Andamans. The chances are nearly two to one that, if a storm occur in this month it will be a violent cyclone. It is also almost a certainty that a storm which forms in this month will advance in a west-north-west direction to the Coromandel coast between Madras and Negapatam. Hence they are chiefly dangerous in the area between the East Ceylon Coast and the Coromandel Coast.

Practical hints for navigating vessels in the Bay of Bengal during cyclonic storms.—When the sailor in the Bay of Bengal has ascertained the bearing and track of the centre of cyclonic storm in the Bay of Bengal he has then to determine what action he will take in order to avoid it so far as possible. The following hints are given chiefly by way of suggestion, and not as rules.

In the case of a steamer there is no doubt that, if the earlier indications of a cyclone be carefully observed, and the position and path of the cyclone be judged with approximate correctness, it is nearly always possible to avoid entirely the inner storm area of a cyclone and to pass out or keep outside of the outer storm area.

It would be out of place in the present book to attempt to give precise instructions how to handle a vessel in order to avoid a cyclonic storm, or cyclone in the Bay of Bengal.

In drawing it up, it has been assumed throughout that it is desirable to state and explain every indication by which the bearing, probable distance and track of the centre of a storm can be estimated and also its intensity, especially so

far as it depends upon the month or period of its occurrence. If the sailor has ascertained these points when he is in the outskirts or outer storm area of a storm, he ought to be qualified to decide which is the best course to take in order to avoid, so far as is possible, the chief dangers to which he is exposed; as, for example, passing into the inner storm area, encountering the hurricane winds of a cyclone or the fierce westerly gales of a cyclonic storm of the rains, or of being carried by the wind and currents of an approaching storm against a lee shore.

Much depends upon whether he is in charge of a steamer or a sailing ship, and whether the vessel is large and well found, and also upon his judgment of the position of his vessel with respect to the coast, as well as to the centre, and upon the strength of the currents produced by the storm.

The object of the sailor ought to be—

1st—to avoid entering the inner storm area;

2nd—if he finds himself involved in the dangerous semicircle, and more especially in the right advancing quadrant, to use every effort to avoid being carried in front of the advancing centre.

He should bear carefully in mind that the right advancing quadrant is the most dangerous, and the left advancing quadrant the least dangerous quadrant in the cyclones and cyclonic storms of the Bay.

He should also remember that in storms near the head of the Bay, or which advance to the head of the Bay, the strongest winds appear to be experienced in the south-east quadrant, or to the south and south-east of the storm centre and that these winds extend to very considerable distances from the centre, and finally merge into the intensified south-west winds which prevail in the south of the Bay. In the case of cyclones or cyclonic storms approaching the Coromandel coast, the strongest winds are usually experienced to the north and east of the storm centre and usually extend to much greater distances to the north than to the south. The right advancing quadrant is very dangerous in the case of these storms.

He should, as soon as he perceives any indications of a storm, and more especially the occurrence of squalls with increasing frequency and strength, use every available indication to judge of its position and character, and not wait until his barometer begins to fall rapidly and winds have increased to the force of a heavy or hard gale, as he will then almost certainly be entering the inner storm area of a cyclone.

He should, even if in command of a well-found steamer, not attempt to pass round a cyclone in the advancing semicircle, unless he has the strongest evidence that the cyclone is at such a distance that he can get well into the left advancing semicircle, or manageable semicircle before the inner storm area reaches him. It is always attended with risk, and cyclones in the Bay are some-

times of very small diameter and advance very rapidly, so that errors of judgment in the distance of a cyclone are very possible. A ship ought on no account to attempt it, except as a last resort.

Hence the advisability that steamers and ships about to proceed to sea from Calcutta when a storm is approaching the Bengal, Orissa or Circars coast, should delay their voyage and stay at Diamond Harbour or in the river until the cyclonic storm has reached land. It is very difficult to estimate correctly the intensity of an approaching storm, and hence the one safe and prudent course for vessels which can only pass out of the river by proceeding at once into the most dangerous quadrant of a cyclone, is to wait until all danger is past by the advance of the storm inland.

In all cases a ship or steamer should be manœuvred so as to increase her distance from the centre as soon as she enters the outer storm area. A steamer can, of course, except under very unusual circumstances, do this, if the storm centre and track be ascertained early and she have sea-room.

If a steamer is in the open sea and finds herself in the dangerous semicircle, she should generally steam slowly against the wind or with the wind on her star-board bow. Mr. Elson notes on this :—

"Owing to the proved incurvature of the winds and the little known set of the sea, also incurving from the same causes as the wind does ; if a steamer has the power to steam head to wind and keep steerage way as did the British man of war *Calliope* in the hurricane at Apia she must naturally be leaving the centre behind her, except, of course, she is right in the storm's path."

In the case of a vessel lying at anchor on the Madras coast or proceeding along that coast, if the centre of severe cyclonic storm be approaching directly towards that part of the coast, she ought especially to avoid passing into the right-hand semicircle and proceed south or south-south-east, so as to avoid the storm. The winds near the coast and the sea in the left advancing quadrant are in this case comparatively light, and there is little or no danger from currents. If in the right advancing quadrant, the commander of the vessel ought to judge of his position as early as possible and proceed well out into the open and keep as far north as is advisable considering his proper course, and then, if proceeding southwards, pass round the storm in the east quadrant. In this case delay in taking the proper action is especially dangerous.

In the case of a sailing ship the following are the rules usually given.

If the vessel be in the right-hand semicircle of a cyclone or cyclonic storm, heave-to on the starboard tack. If in the left-hand semicircle run, keeping the wind on the starboard quarter, if possible. When the squalls decrease and the barometer rises, if necessary, heave-to on the port tack if it is desired not to proceed too far from the proper course.

It is sometimes not expedient to run in the manageable or left-hand semicircle, in which case it is usual to heave-to on the port tack.

It should be especially remembered that the south-west winds are always intensified in the south of the Bay during the existence of a cyclone or cyclonic storm in the north of the Bay. The barometer at this stage gives practically no indication of the distant storm. But on approaching the outskirts of a storm in the Bay from the south, the squalls begin to increase in intensity and frequency, and in that case it is advisable to exercise great caution in running up the Bay, as in many cases in recent years where this caution has not been exercised vessels have been carried into the inner area and suffered severely.

It should be carefully noted that these suggestions are based on the information supplied in recent years to the meteorological office by ship-masters. Sailors should, in utilising any portion, carefully exercise their own judgment and remember Piddington's observation that in such matters "absolute rules are all nonsense."

A brief summary of these rules for the guidance of sailors will be found printed on card board in volume II of this Hand-Book giving the plates and charts referred to in volume I.

I cannot conclude this chapter better than with the following extract from the pamphlet entitled "The law of storms" by Dr. W. Doberck, the Hongkong Meteorologist :—

"The master of a vessel after encountering a severe typhoon (or cyclone) has often to undergo the vexation of seeing every manœuvre of his subjected to the comments of those unaware of the hundreds of things he has to take into consideration beside the law of storms and who were comfortably ensconced in their houses, while he was experiencing the storm with its fierce gusts, interrupted by the, if possible, more ominous lulls during which he cannot see three ships' lengths before him, the mountainous waves in which his good ship is but a "cockboat" the loudest shouting inaudible, drowned in the roar of the tempest, boats and everything moveable having been washed overboard, rudder gone and perhaps one of the masts thumping at her bottom, while the seas threaten at every moment to swamp the ship. So, too, let us be charitable and learn to withhold censure even though it may seem the hapless ship master has erred in his judgment. We are all sometimes very wise after the event."

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